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Reliability analysis of non-linear (p-y) laterally loaded piles embedded in stiff clay below water table

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RELIABILITY ANALYSIS OF NON-LINEAR (p-y) LATERALLY LOADED PILES EMBEDDED IN STIFF CLAY BELOW WATER TABLE

(Volume 1)

BY

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ABSTRACT

Laterally loaded piles are used in some of the very important structures. Therefore, the economical design of such piling is necessary, in which a proper balance among initial cost, risk of failure, and consequences of failure is achieved.

Like the other geotechnical structures, uncertainty is inherited in the laterally loaded piles. When researchers and design engineers face the uncertainty in the structure, they opt for factor of safety, which is a conservative approach. Instead, reliability analysis provides a systematic account of the uncertainties and a rational procedure for design.

In reliability analysis, parameters connected to pile material, surrounding soil and applied load are taken as random variables and they are best estimated without conservatism by taking their mean value and uncertainty is taken care of by the variance.

In this study the performance of laterally loaded pile structure is checked for strength and serviceability through reliability analysis.

Dedicated To My Family

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CHAPTER 1

INTRODUCTION

1.1 Overview

When offshore platforms were being installed in significant numbers in the 1950s, engineers realized that correct solutions required that the ways be found to link the soil response to the lateral deflection of pile. Number of individual studies and studies backed by API (American Petroleum Institute) were conducted on full-scale, and 1g model piles (Shibata et. al., 1989), which has ultimately given the p-y curves for various soils that yielded excellent agreement with the response of the piles. After that, Reese (1974, 1975), Matlock (1970), Meyer (1979), and many others have published papers on the deterministic analysis of laterally loaded piles.

Like most of the structures, uncertainty is also associated with the loadings and capacities of laterally loaded piles. Thus absolute safety or zero probability of failure cannot be achieved. Structures must be designed to serve their function with a finite probability of failure. When there is uncertainty, in the deterministic analysis, engineers use the factor of safety based on their experience, which is a conservative estimate of the design parameters. On the contrary, with probabilistic analysis, economical design can be achieved by properly balancing the risk of failure, consequences of failure, and the initial cost. In probabilistic analysis, the uncertainty about a random design variable is described by a cumulative distribution function and probability density function. In reality, it is very difficult, if not impossible to get the distribution function of random variable. The information or data available may be only sufficient to evaluate the mean and variance or

standard deviation of random variables. Consequently, practical approach is to go for reliability analysis, which only needs mean, variance, and/or coefficient of variation (COV) of random variables to evaluate the reliability indices for structures.

It is certainly beneficial if reliability analyses are conducted in addition to the conventional deterministic approach especially for a complex structures such as offshore structures. Some of the examples include Artificial Island in the Arctic (Watt et al. 1984), and Gravity Platform (Wu et al. 1983). In case of Artificial Island, when they conducted the deterministic analysis, it ends up with the safety factor of 0.5. That shows that the deterministic analysis give very conservative result. After that, reliability analysis was carried out and they got highest failure probability of 0.007 i.e. minimum safety factor of 1.9.

1.2 Objective

The main goals behind conducting study on the laterally loaded single isolated pile and pile group surrounded by stiff clay below water table are:

1) To acquire the dimensionless parameter i.e. coefficient of variation (COV) for the functions of random variables such as maximum bending moment in pile M_{Max} (Ultimate Limit State) and maximum pile head deflection Y_{Top} (Serviceability Limit State). The important benefit of the dimensionless analysis is that the number of random design variables such as pile properties, soil properties surrounding the pile and the lateral load on pile head in a complex problem like the non-linear behavior of laterally loaded piles is reduced to dimensionless parameter.

2) To evaluate the degree of influence that each of the major random design variables has on the performance of laterally loaded pile and pile group.
3) To obtain the maximum limit up to which any specific random design variable can vary for specific case and further variation in it cause the failure of structure.
4) To assess the significance of length (short or long), and type (single isolated or pile group) of piles, and the boundary condition at pile head.
5) To check that the applied lateral load is causing the soil reaction (resistance) for which portion of the p-y curve (linear, first parabolic, second parabolic, second straight, and plastic stage portion), at a specific depth.
6) To analyze the effect of random design variables on the reliability indices of the structure.
7) To make bases for further research on laterally loaded single piles and pile group with more complex loads such as cyclic and dynamic load.

1.3 Methodology

Like the other geotechnical structures, uncertainty is inherited in the laterally loaded piles. In the conventional deterministic method, engineers go for the conservative estimates by taking factor of safety to deal with the uncertainty, but, in this study we use the more objective reliability analysis. Reliability analysis provides a systematic account of the uncertainties and a rational procedure for design. In reliability analysis, all the random variables are best estimated without conservatism by taking their mean value and uncertainty is taken care of by variance or standard deviation of random variables. This study will go through the following steps:

1) Decide about the major random design variables affecting the performance of structure.
2) Calculate the relative stiffness factor 'T' to decide on the length of piles.
3) Decide the boundary conditions: free head, fixed head, or pure moment.
4) Feed the value of random design variables, length of pile, type of soil, and the boundary constraints into the computer program COM624P to get the value for maximum bending moment in single isolated pile (associated with strength) and pile head deflection (associated with serviceability). These values are later used in probabilistic modeling and to conduct reliability analysis.
5) In case of group of piles, use computer program FB-MultiPier to satisfy the above step.

   Note: The emphasis of the research is on the development of the reliability analysis. The soil mechanics aspects of building the p-y curves are beyond the scope of this work i.e. it is assumed that the program COM624P and FB-MultiPier are using the proper p-y curves for the given soil type.
6) Formulate the probabilistic modeling by varying each random design variable at 5% rate.
7) Probabilistic modeling confers the statistics for variance of strength and serviceability parameter. By means of those figures acquire the dimensionless parameter coefficient of variation (COV) for maximum bending moment in pile and pile head deflection (explained in detail in Chapter 5).
8) Obtain the value for mean and COV for resistance parameter of pile from the codes and other available literature.

9) Using mean and variance of strength, serviceability, and resistance parameters, conduct the reliability analysis to get reliability indices (β).

10) Check the safety or reliability of structure by comparing calculated reliability indices with the maximum allowable limit.

1.4 Organization of thesis

This thesis is divided into four parts. The first part comprises the introduction and literature review, which discusses the geotechnical and probabilistic background, previous developments, and engineering and probabilistic material related to this study. The second part describes and applies the methodology customized to analyze the laterally loaded single isolated pile or pile group embedded in stiff clay below water table. The third part carries out the discussion on the results, presents some conclusions, and suggestions for future studies. The last part comprising Appendices shows all the results of the analysis in table and chart form.

This thesis has seven chapters and 13 Appendices. Chapter 1 is an introduction to the study; it also includes objectives and the methodology used to get solution.

Chapter 2 presents the literature review, which is divided into three sections. First section carries out the general discussion on the analysis of laterally loaded piles, also gives the idea about the past work related to this topic. The second section is concentrated on the pile group. The third section is related to the reliability analysis. It explains what reliability analysis is and why and when we need it.

Chapter 3 describes all the general theoretical terms related to the analysis of laterally loaded pile or pile group surrounded by stiff clay below water table.

Chapter 4 deals with the general terms and formulation used for probabilistic modeling and reliability analysis.

Chapter 5 formulates the customized procedure to compute the variance and the dimensionless parameter COV for random design variables, strength parameter, and serviceability parameter. Further, it shows steps and sample calculation to conduct reliability analysis on laterally loaded single isolated pile and pile group.

Chapter 6 provides an in-depth discussion on the results of the analysis. It also gives the comparison with the past studies.

Chapter 7 gives the conclusion that came out of the study and recommends areas for further research.

In addition to above chapters, thesis includes following Appendices.

Appendces A and B shows the input and output file for computer program COM624P Version 2.0 and FB-MultiPier Version 4.0.

Appendices C TO F presents the analysis results for single isolated pile in form of tables and charts.

Appendices G TO L illustrate the analysis results for pile group.

At the end, Appendix M presents the results of combined load analysis on free head single long pile.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Three general methods are used to analyze the behavior of piles loaded with static loads:

- Linear-elastic method.
- Ultimate load method.
- Nonlinear p-y method.

The linear procedures include the subgrade modulus concept for soil and the elastic continuum concept (Evans & Duncan 1982). Design procedures based on these linear concepts have been developed which are relatively easy to use. A major problem with using these procedures is the determination of an appropriate reaction modulus (E_{py}), as it varies with pile properties, soil properties, depth below the ground surface and the pile deflection.

Limit analysis procedures (Evans & Duncan 1982) may be used to estimate the ultimate lateral pile capacity for a given set of soil and pile properties, but the deflections of piles at working loads cannot be calculated using these procedures.

The nonlinear p-y procedures provide the best fit between the calculated behavior of the laterally loaded piles and the behavior measured in full scale tests. Criteria are available to describe the soil behavior in terms of the soil strength parameters

Φ and C. Because of the complicated nature of the analysis procedures, it has been necessary to perform computer analysis for this type of solution.

2.2 Soil Reaction Modulus

The main parameter for the soil in the design of a pile under lateral loading is a soil reaction (subgrade) modulus, defined as the resistance of the soil at a point along the pile divided by the deflection of the pile at that point. The soil reaction modulus is a function both of depth below the ground surface z and the deflection of the pile y.

The sketch in Figure 2.1(a) shows a cylindrical pile under lateral load with a thin slice of soil shown at the depth below the ground line z_1. The uniform distribution of the unit stresses normal to the wall of the pile in Figure 2.1(b) is correct for the case of a pile that has been installed without bending. If the pile is caused to deflect a distance y_1, the distribution of unit stresses would be similar to that shown in Figure 2.1(c). The stresses will have decreased on the back side of the pile and increased on the front side. Some of the stresses will have both a normal and a shearing component. Distribution of the unit stresses will result in the quantity called soil reaction (p_1) which acts opposite in direction to y_1. The dimensions of soil reaction are load per unit length along the pile. These units are identical to those in the solution of the ordinary equations for a beam on an elastic soil.

The soil reaction modulus can be defined as the slope of the secant to a p-y curve (Figure 2.1(d)) and it is denoted by E_{py}. While E_{py} will vary with the properties of the particular soil, the term does not uniquely represent a soil property. Rather E_{py} is simply a parameter for convenient use in computations.

In a notable paper, and one that is still being used, Terzaghi (1955) discussed a number of important aspects of soil reaction modulus, including the resistance of the soil to lateral loading of a pile. Unfortunately, while his numerical recommendations reveals

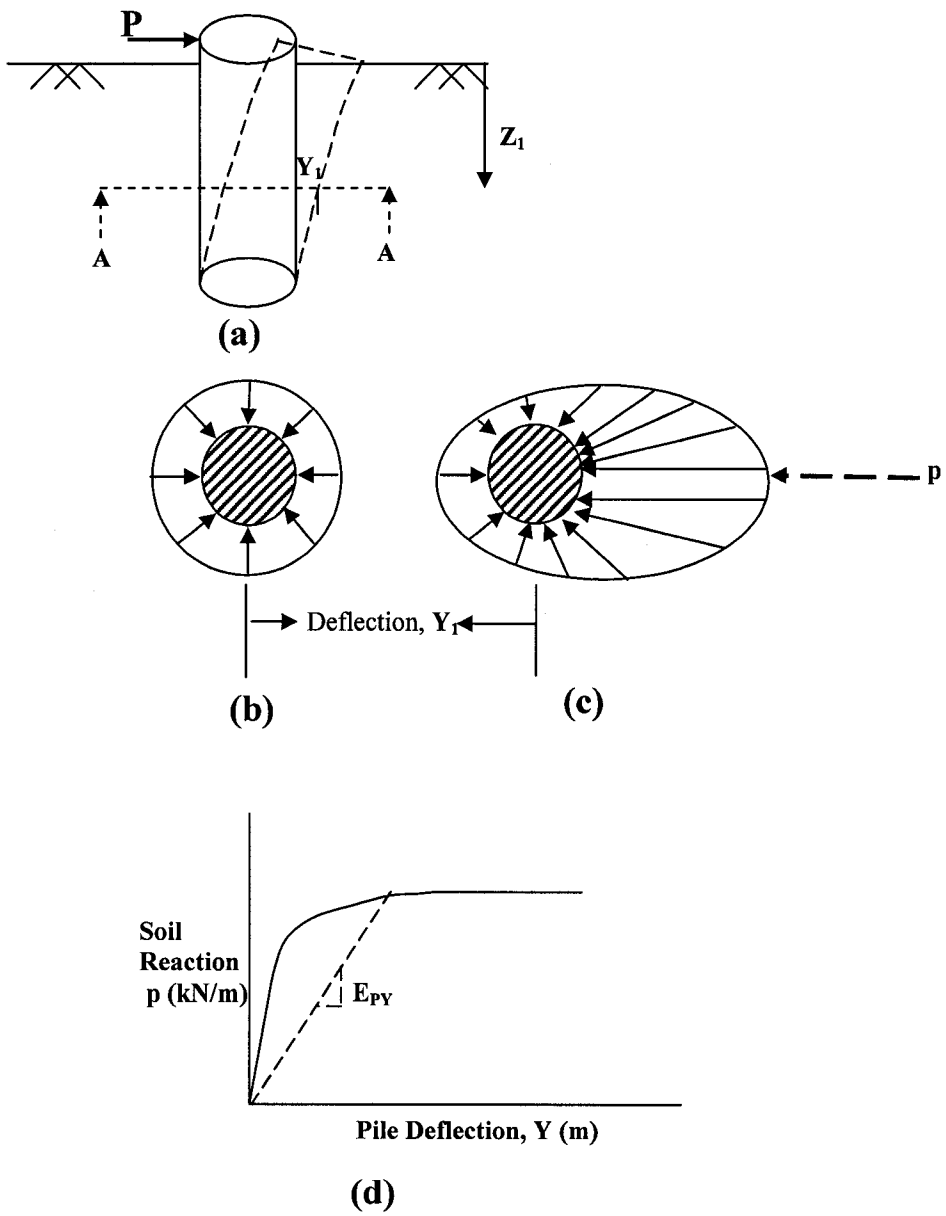


Fig. 2.1 Soil reaction against a pile before and after lateral deflection (Reese, 2001)

that his knowledge of the problem of the pile was extensive, he failed to give any experimental data or analytical procedure to validate his recommendations.

In 1958, McClelland and Focht, introduced a method called **p-y method** to take into account the nonlinearity of soil reaction modulus. In their paper, curves were included from the analysis of the results of the full scale, instrumented, lateral-load test. They concluded that soil reaction modulus is not just soil property but it is a function of the pile diameter and deflection, and soil properties.

Matlock (1970) measured the bending moment accurately by using strain gauges and then he integrated the bending moment curve twice to get deflection. After that API (American Petroleum Institute) sponsored an extensive research on laterally loaded piles and in 1987, they recommended the general practice for planning, designing and constructing offshore platforms.

2.3 Pile Groups

Piles are usually installed in groups and the response of a laterally loaded pile within a group of closely (when center-to-center spacing between piles is less than 6 times pile diameter) spaced piles is very different from that of single isolated pile. This difference in the behavior is due to the fixity and lateral resistance (Mokwa & Duncan 2001) provided by pile cap and the interaction between pile and soil (pile-soil-pile interaction). It is noted that lateral deflection and the maximum bending moment in a group is greater than that of a single pile at the same load because the soil behaves as if it has less resistance, allowing the group to deflect more when subjected to the same load per pile.

The easiest way to analyze the pile group is to assume that the pile cap is rigid and only axial load is applied. In the beginning, under these assumptions, many of the investigators have presented their work, such as Culmann in1866 (Terzaghi 1956),

Brennecke & Lohmeyer in 1930 (Terzaghi 1956), Westergaard in 1917 (Karol 1960), Nokkentved in 1924 (Hansen 1959), Vetter (Terzaghi 1956) in 1939. However, in 1950, Hrennikoff considered a laterally loaded pile as an elastic beam on an elastic foundation with uniform stiffness and this was the method which presents the potential for the analytical treatment of the pile-soil interaction system. All of the subsequent research has followed the approach taken by Hrennikoff. Later, Aschenbrenner (1967), extended the Hrennikoff's method to the three dimensional case but it was restricted to pin-connected piles only. Saul (1968), generalized the matrix method for a three dimensional foundation.

Reese & Matlock (1960, 1966) and Reese et al. (1970) used the finite difference method for the analysis of laterally loaded single pile and pile group. They initiated the use of digital computer for the analysis of laterally loaded piles.

2.3.1 Analysis of closely spaced pile group

In case of the analysis of laterally loaded single pile, the p-y curve method is being used. The same method can be applied to the analysis of piles in a group. If the piles are spaced very far apart (pile spacing>6D), the same p-y curve can be used which is used for the analysis of single pile. When the piles are installed close to each other, the lateral resistance from the soil will decrease because of the pile-soil-pile interaction effect and hence ultimately the pile's efficiency to carry load decreases. After the thorough investigation, it is concluded that the most effective way to take into account the loss of efficiency for such piles is to develop procedures for reducing the value of maximum soil resistance (p_{ult}) to reflect the close spacing, which in turn will reduce all p-values (soil

resistance) in the p-y curve. The ultimate soil resistance on a pile is also affected by the adjacent piles due to the interference of the shear-failure planes called shadowing effect.

Focht & Koch (1973) used an elastic theory to propose a model that combines the p-y method of single pile with the group effect. They suggested a y-factor for deflection and p-factor may need to be applied to the p-y curves in cases where shadowing effects occur. Modifications can be done as shown in Figure 2.2 with p-values multiplied by (α_1) and y-values multiplied by (α_2). Values for α_1 and α_2 are less than 1.

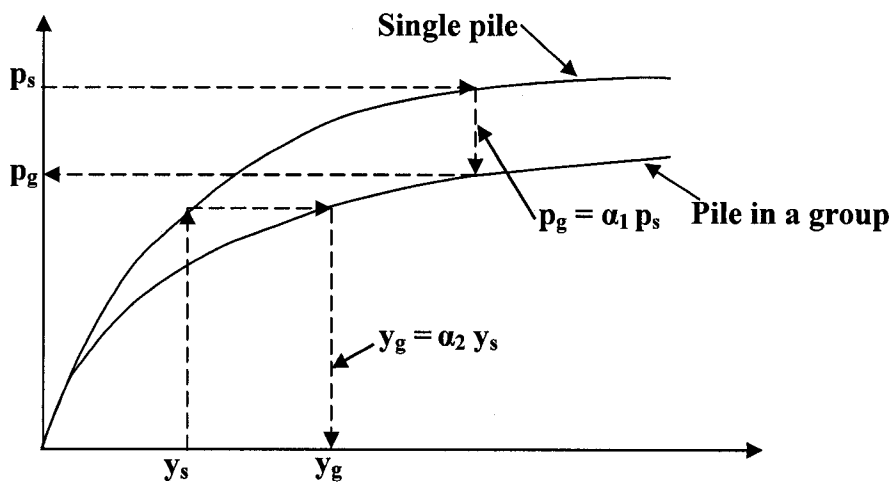


Fig. 2.2 Modification of p and y to get p-y curve for piles in a group (Reese, 2001)

Brown et al.(1988) suggested a way to account for the group effect by using the p-multipliers. The p-multipliers are empirical values which are obtained from the load tests on pile groups. As they are determined from load test results, the multipliers include both the elastic effects and the shadowing effects. This eliminates the need for a separate y-multiplier, which is found in elasticity-based theoretical methods. The value of p-

multiplier is always less than one, thus the value of soil resistance at any value of deflection for pile group is less than that of single pile at given load.

Many of the researchers such as Prakash and Saran (1967), Franke (1988), Lieng (1989), and Rao et al. (1996) concluded that the group effects diminish when center-to-center spacing between piles parallel to the lateral load exceeds 6 pile diameters, and when the spacing perpendicular to the load exceeds 3 pile diameters.

To check the factors affecting the efficiency of the pile groups subjected to lateral loading, 14 tests were conducted. The conclusion was that the pile spacing, group arrangement, and group size have the most significant effects and other factors such as pile-head fixity, soil type and soil density (Brown & Reese 1985, Morrison & Reese 1986, Brown & Shie 1991, McVay et al. 1995), and pile displacement are secondary.

2.4 Reliability Analysis

2.4.1 Introduction

All geotechnical engineering projects start with site exploration and soil testing to obtain the properties and distribution of soil. After that analysis is conducted to estimate the response of the soil under applied load. Errors, often of unknown magnitude, are introduced in all three phases of a project. Over 40 years ago, Casagrande (1965) mentioned that there should be a proper balance among the risk of failure due to these unknown errors, consequences of failure, and the initial cost. To achieve above mentioned criteria, geotechnical engineer uses the conventional factor of safety approach, which is based on experience and it is logical too. However, it is very common to use the same value of factor of safety for different kinds of design, such as long-term slope stability, without regard to the degree of uncertainty involved in its calculation. The same

value of factor of safety is applied to the widely varying degree of uncertainty. On the other hand, reliability analysis differentiates between the situations where the uncertainties are particularly high or low and also it takes into account the combined effect of uncertainties on structure. Christian et al. (1994) express some words about reliability method:

"Reliability analysis is especially useful in establishing design values for factor-of-safety representing consistent risks for different types of failure..... The most effective applications of probabilistic methods are those involving relative probabilities of failure or illuminating the effects of uncertainties in the parameters."

In spite of the benefits over the conventional method, geotechnical engineers hesitate to use reliability method because of two reasons:

- Compare to the variability of man-made manufacturing material used in structures, geotechnical variability is a complex attribute that results from many disparate sources of uncertainties.
- It is general prospect that reliability method requires more data, effort, and time than available in most circumstances.

Many of the structural related reliability-based design codes have been put into practice in mid 1970s, such as BSI 1972; CSA 1974; NKB 1978; ACI 1983. However geotechnical design community has been slow in assimilating this new design methodology.

Ruiz (1984, 1986) analyzed the laterally loaded pile in soft clays using the reliability analysis (First-Order Second-Moment method). Folse (1989) also used the same (FOSM) method for the lateral displacement of the pile top and for first yielding of

pile material. The pile was loaded with set of forces and moments and randomized p-y curve was used. Using the single axially loaded piles, single laterally loaded piles and pile groups, API (American Petroleum Institute) has conducted a comprehensive reliability analysis to evaluate the error, optimum cost, and reliability associated with the conventional method for offshore pile design. Hansen, Madsen & Tjelta (1995), considered the pile-soil interaction in their study. Also, Christian et al.(1994), and others have described excellent examples of the use of reliability in geotechnical engineering.

2.4.2 Methods of Reliability Analysis

The area of the structural reliability has grown at a tremendous rate in last few decades. Many methods have been proposed and by using these methods of reliability, we can analyze any type of failure mode i.e. yielding, plastic collapse, excessive deformation, buckling, fracture, creep, fatigue, etc.

2.4.2.1 Stress-Strength Interference Method

It is one of the earliest methods used for structural reliability analysis. Now a day even though many advanced methods of reliability analysis are available, the stress-strength interference method is still widely used in many industries because of its simplicity, ease of use, and economy. It assumes that stress and strength are statistically independent parameter, which is not right for all cases.

Sundararajan (1986), derived a stress-strength equation for general failure criteria and it is given by:

$$P_f = \int_{-\infty}^{\infty} F_C(l) F_L(l) dl \quad \text{..... (2.1)}$$

where P_f is the probability of failure and $F_L(.)$ and Fc(.) are the cumulative density functions of L, *l* (load) and C (Capacity), respectively. Analytical and tabulated results for the above equation are available for variety of cases.

In many places, the stress strength interference is also represented by graph (Figure 2.3). The figure represents the pdf (probability density function) of stress (load) and strength (capacity) and their interference. The overlapped area in the figure is directly proportional to the failure probability, as long as the mean value of stress is less than the mean value of strength. The failure probability is equal to the black area in Figure 2.3.

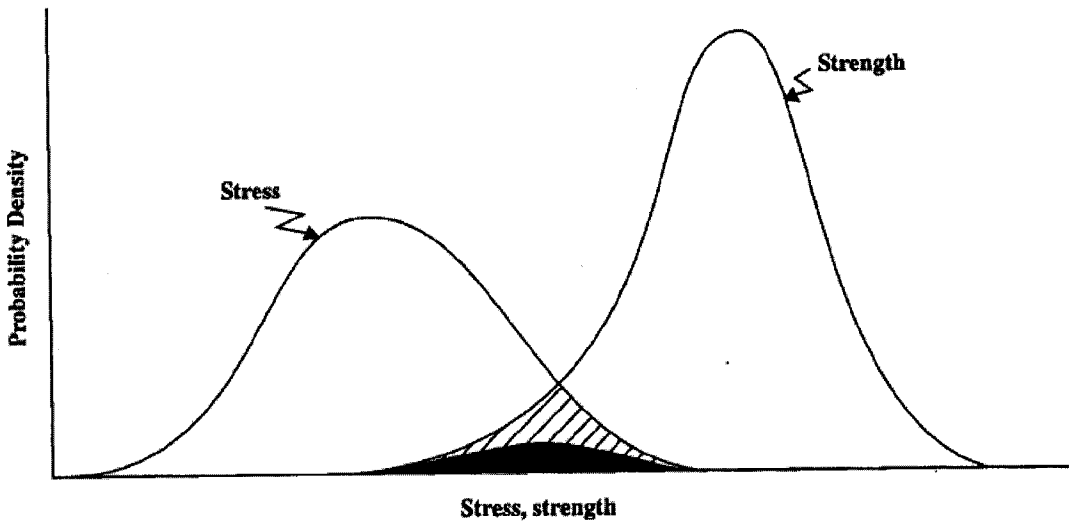


Fig. 2.3 Schematic diagram of stress-strength interference

2.4.2.2 First-Order and Second-Order Reliability Methods

These methods require more computation than the stress-strength interference method, but they are less restrictive, require less simplifying assumptions, and are applicable to broader class of problems.

For reliability analysis we need joint density function of random variables (i.e. load and capacity), which is practically impossible to get. Even if this function is available, the evaluation of the multiple integral is extremely complicated. Therefore one possible approach is to use analytical approximations of this integral that are simpler to compute and which can be achieved by First- and Second-Order Reliability methods.

When the limit state function is a non-linear function or linear function of uncorrelated random variables, First-Order Reliability method can be used to evaluate the problem. Second-Order Reliability method estimates the probability of failure for linear limit state function with correlated non-normal random variables or non-linear limit state function.

First-Order Reliability method is explained in detail in Chapter 4.

2.4.2.3 Simulation Based Reliability Methods

The most renowned simulation method is Monte Carlo simulation technique. Herein a computer based analytical model is developed to predict the behavior of a system. If any uncertainty is involved in it, then the model is evaluated several times. Each simulation cycle is based on a certain randomly selected set of input parameters of the system. The definition of input parameters should include their moments and distribution types. Output parameters are obtained from the simulation of model. Then, statistical methods are used to get mean, variance, or distribution type of output parameters.

Simulation based reliability method also include variance reduction techniques such as the importance sampling method, stratified sampling method, adaptive sampling method, latin hypercube sampling method, antithetic variates method, conditional

expectation method, generalized conditional expectation method, and response surface method.

Details of above topic are available elsewhere, Marek, Gustar, and Anagnos (1996), Ross (1997), and Ayyub and McCuen (1997).

2.4.2.4 Probabilistic Finite Element Method

The application of the methods mentioned in previous sections is limited to simple structures with linear constitutive behavior. But, if the geometry of the structure or loads applied on it is more complex, and if the material behavior is non-linear, more advanced computational tools, such as finite element method or boundary integral equation methods have to be employed in conjunction with statistical method such as First- and Second-Order Reliability method to analyze complex structures.

The perturbation method has been used extensively in developing the probabilistic finite element method because of its simplicity and versatility. Many researchers have used this method successfully to analyze structure (Baecher & Ingra 1981; Shinozuka & Deodatis 1988).

The details of this method are available elsewhere- Probabilistic Structural Mechanics Handbook by C. (Raj) Sundararajan (1995).

2.4.3 Risk Assessment

Unfortunately, there are no generally accepted definitions of the term risk. United States Society for Risk Analysis recommended that a single definition of risk not be established but that everyone is free to define it as appropriate to his or her own work. The risk is assessed based on the situation. The risk that may affect a large number of

people simultaneously (i.e. failure of dam) are less tolerable than risks of individual accidents.

Failure rates can be either collected or evaluated theoretically for the common class of structures. Suppose the collection of data for annual failure rate of earthen dams, from all causes, is about 10^{-4}. By no means does this constitute an acceptable rate. So, how can this information be used to establish allowable risks for specific projects? The first effort was made by Greg Baecher and after making some changes Whitman reproduced and published it in 1984 (Figure 2.4). British Columbia Hydro has also made an effort to assemble information, as shown in Figure 2.5, to review multi-hazard threats to dams and other facilities (Nielsen et al.1994). The minimum risk shown for one fatality is 10^{-4}/year and the risk level gets down with more number of fatalities. This approach is explained in detail by Vick and Stewart (1996).

After the risk assessment, we get expected cost of failures for a project. By taking into account this expected cost of failure and other costs such as initial and maintenance cost, we can theoretically evaluate the project to get optimum value of reliability index (Probability of failure).

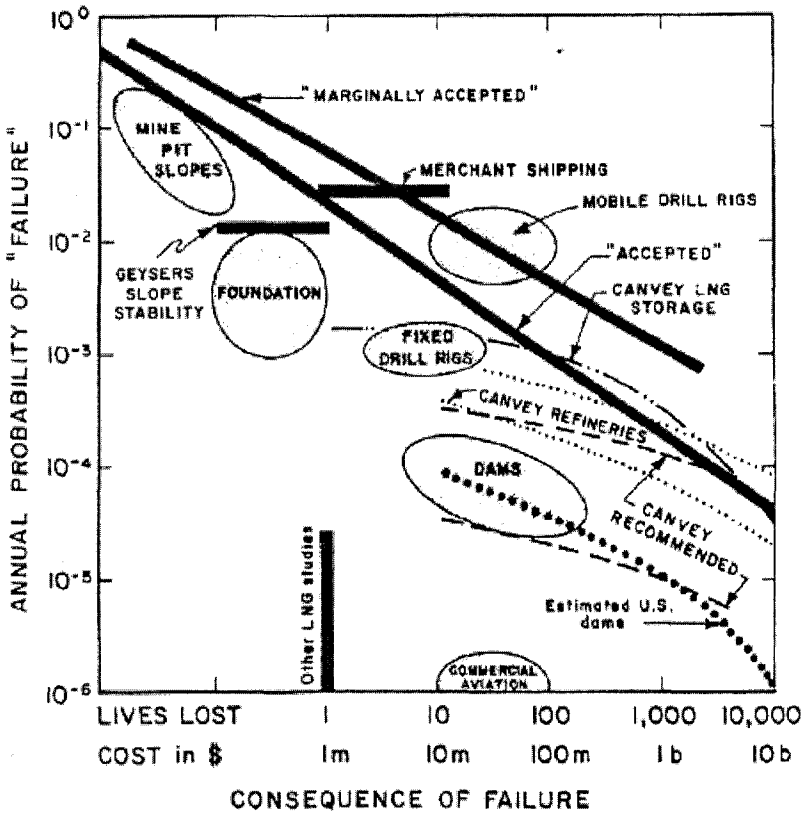


Fig. 2.4 Risks for Engineering Projects (Whitman 1984)

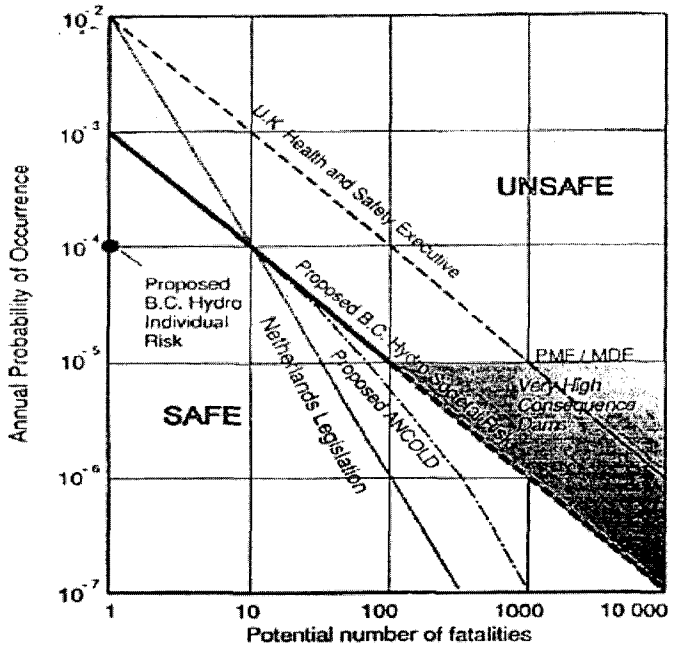


Fig. 2.5 Different Risk Criteria (Courtesy of BCHydro)

CHAPTER 3

THEORY OF LATERALLY LOADED PILE

Designer starts his work by selecting appropriate material with required durability for pile foundation. Next, he makes sure that the single pile or the critical pile in group of piles, is safe against the collapse and serviceability bounded deflection due to axial load, lateral load, and the overturning moment. If the load on a single pile or group of piles is purely axial, then it can be analyzed by simply, solving the equation of static equilibrium. In contrast to that, if the lateral loading is applied, analysis goes through the cumbersome solution of nonlinear differential equation.

For the analysis of laterally loaded pile, five major things should be important to know,

1. Type of laterally loaded pile.
2. Nature of loading.
3. Type of boundary condition at pile head.
4. Type of soil around the pile (to choose appropriate p-y curve and other soil properties).
5. Type of method or model used for analysis (discussed in Chapter 2).

3.1 Types of laterally loaded pile

Based on their use in engineering practice, laterally loaded piles are divided into two major sectors:

3.1.1 Active piles

In case of active piles, the loads are applied mainly on top. This sector includes, the pile foundation for offshore platforms, bridges, high-rise structures, overhead signs, mooring and breasting dolphins.

3.1.2 Passive piles

When the loading is applied along the length of pile, the pile comes in category of passive piles. Examples include retaining wall and piles in a moving slope.

3.2 Nature of loading

In case of active pile, four types of loading can be identified as static, cyclic, sustained, and dynamic. In addition, for passive pile, the loading along the length can occur due to moving soil.

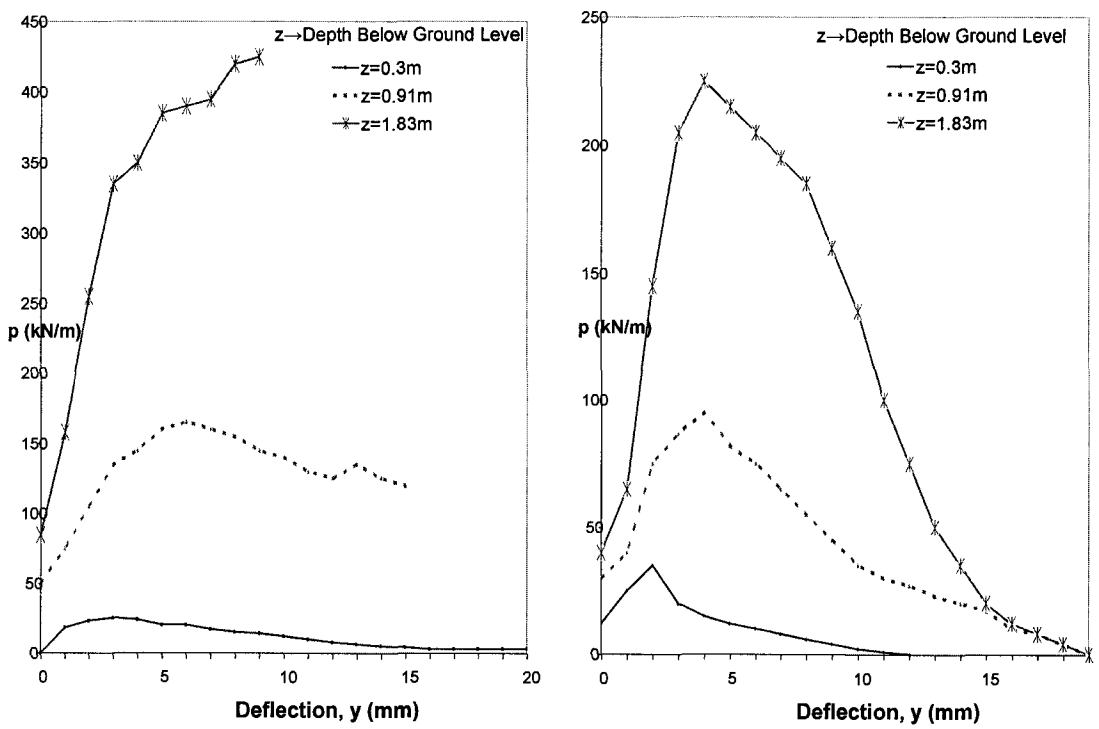
3.2.1 Static loading

It is a short term, monotonic loading applied to a pile. In real design, it seldom comes in use, but the p-y curve obtained from this kind of loading can be used as a baseline for representing the effect of other more complicated loading. Also for some

kind of clays and sands, this curve can be used to imitate sustained loading. The p-y curve for stiff clay from static load test is shown in Figure 3.1(A).

3.2.2 Cyclic loading

When the cyclic load is applied to the pile, in the beginning the soil resistance is same as the one for static load for the given deflection but as the deflection of pile head increases, the soil resistance decrease rapidly in case of cyclic loading (as shown in Figure 3.1(B)).



(A) (B)

Fig. 3.1 The p-y curve developed for stiff clay from (A) Static load, and (B) Cyclic load test of 641mm diameter pile (Reese et al. 1975)

The effect of cyclic loading is not very profound in case of sands and stiff clay above water level, whereas, for saturated clay below water table, loss of soil resistance due to cyclic loading can be serious. Experiments by Reese et al.(1975), shows that stiff clay is pushed away from a pile on ground surface due to cyclic loading. When next cycle of load is applied, water comes out of the opening with force and cause scour of clay with additional loss of soil resistance.

We can see cyclic loading in laterally loaded structure such as offshore structure, bridges, mooring and breasting dolphin, overhead signs, etc.

3.2.3 Sustained loading

It's the kind of loading when load stays on structure for longer period of time. Sustained loading causes more deflection than static load. Over-consolidated clays and granular soils are not much affected by sustained loading. Analytical solution for sustained loading is not available in theory yet because the parameters it needs is not clearly defined, rather in some cases we can solve it by experiments (Pyramid Building in Memphis, Tennessee) (Reuss et al. 1992).

3.2.4 Dynamic loading

Laterally loaded pile can be subjected to the dynamic load such as earthquake, vibration from machines, vehicle's traffic on bridges, and installation of pile besides the existing pile. For the static load case, soil resistance can be relating with the stress-strain characteristics of the soil, but for dynamic load, inertia effect comes into account too. Thus, the p-y curve cannot be directly used for analysis of piles in case of dynamic loading. On top of that, for granular soil, liquefaction of soil happens. Details are

given elsewhere: Woods & Stokoe (1985); Gazetas & Mylonakis (1998); Ramshaw et al. (1998).

3.3 Boundary condition

Analysis of laterally loaded pile requires the solution of beam-column differential equation and to solve this equation, boundary conditions need to be specified. Without the boundary condition the structure is considered as free body. Three common boundary conditions at the top of the pile are:

- **Free Head:** As shown in Figure 3.2(a), the top of the pile can freely rotate and move in lateral direction when subjected to horizontal load and/or moment.
- **Fixed Head:** The pile is embedded in a pile cap or other structure, which is assumed to be stiff enough to prevent rotation of the top of the pile but pile can move laterally. Figure 3.2(b).
- **Pure Moment:** When the vertical load of super-structure acts eccentrically at the foundation. In this case, pile top can rotate but can't move laterally. Figure 3.2(c)

Above three situations are adequate to analyze any laterally loaded pile, but for other boundary conditions, refer Reese & Van Impe (2001).

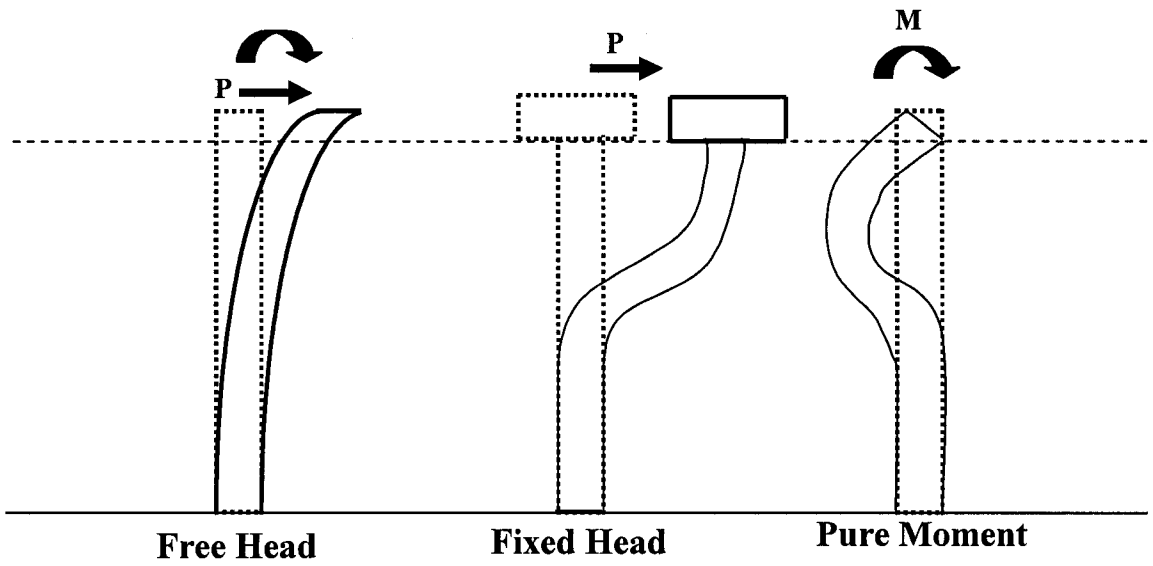


Fig. 3.2 Boundary conditions at pile head

3.4 Selection of p-y curve

Although, the p-y curves for various soils are obtained from the full scale field tests, it is very arduous and cumbersome to take direct measurement of p and y from field. The simple and successful method, which all the researchers have used, is to use strain gauges for the measurement of bending moment in the pile. Integration of bending moment curves twice gives the deflection (y) of pile and by differentiating it twice; we get soil resistance (p).

As this thesis is concentrated on topic of the analysis of laterally loaded pile in stiff clay below water table, only p-y curve for stiff clay below water table is explained in detail.

3.4.1 Description of p-y curve for stiff clay below water table

The procedure to build p-y curve for stiff clay below water table for static loading is very well presented by Reese et al. (1975). Graphical representation of p-y curve is shown in Fig. 3.4. The procedure includes following steps:

1) By doing laboratory tests, get the value of undrained shear strength (C_u), submerged unit weight (γ'), and ε_{50} from soil sample. Also get the value of pile diameter (B). Value of ε_{50} is also given in Table 3.1.

Table 3.1 Values of ε_{50} for overconsolidated clays.

	Average Undrained Shear Strength (kPa)		
	50-100	100-200	300-400
ε_{50}	0.007	0.005	0.004

2) Calculate the average undrained shear strength (C_a) over the depth Z.

3) Calculate Ultimate soil resistance (p_c) per unit length of pile;

$$p_{ct} = 2C_aB + \gamma' BZ + 2.83C_aZ \quad \text{..... (3.1)}$$

$$p_{cd} = 11C_uB \quad \text{..... (3.2)}$$

Take smaller of p_{ct} (associated with top part of pile) and p_{cd} (associated with lower part of pile), as ultimate soil resistance (p_c).

4) Get the initial linear portion of p-y curve shown in Fig. 3.4, by using following equation;

$$p = (k_sZ)y \quad \text{..... (3.3)}$$

Value of soil modulus (k_s) is given in Table 3.2.

Table 3.2 Values of soil modulus (k_S) for over-consolidated clays.

	Average Undrained Shear Strength (kPa)		
	50-100	100-200	300-400
k_S (MN/m3)	135	270	540

5) Get the first parabolic portion of p-y curve (Fig. 3.4) from following equation,

$$p = 0.5 p_c \sqrt{\frac{y}{y_{50}}} \quad \text{..... (3.4)}$$

Where,

$$y_{50} = \varepsilon_{50} B \quad \text{..... (3.5)}$$

The first parabolic portion, starts from the point where linear portion ends and it ends when deflection (y) becomes equal to $A_s y_{50}$.

6) Get the value of A_s (for static loading) from Fig. 3.3 for specific non-dimensional depth.

7) Get the second parabolic portion of p-y curve (Fig. 3.4),

$$p = 0.5 p_c \sqrt{\left(y / y_{50}\right)} - 0.055 p_c \left(\frac{y - A_s y_{50}}{A_s y_{50}}\right) \sqrt[4]{\frac{y - A_s y_{50}}{A_s y_{50}}} \quad \text{..... (3.6)}$$

Range of second parabolic portion is from y equal to $A_s y_{50}$ to a point where y is equal to $6A_s y_{50}$.

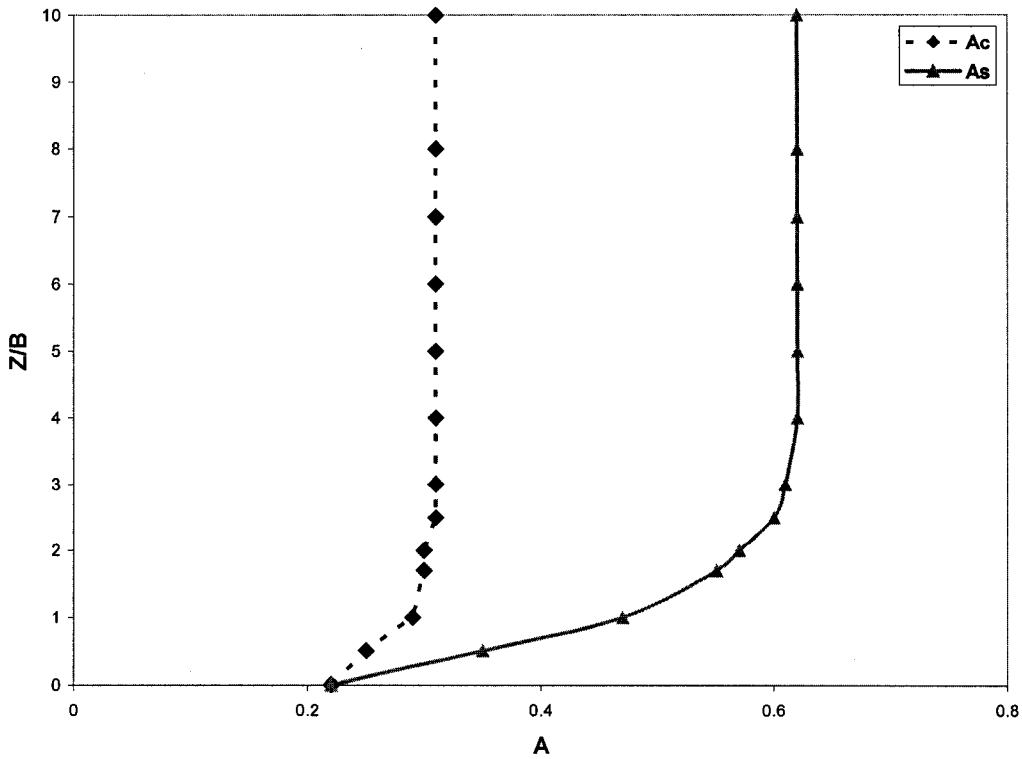


Fig. 3.3 Values of constants A_s (Static) and A_c (Cyclic) (Reese, 1975)

8) Get the second straight portion (linear softening) of p-y curve (Fig. 3.4),

$$p = 0.5p_c\sqrt{6A_s} - 0.411p_c - \frac{0.0625}{y_{50}}p_c(y - 6A_s y_{50}) \quad \text{..... (3.7)}$$

Above equation is valid for the value of y between $6A_sy_{50}$ to $18A_sy_{50}$.

9) Get the last straight portion (plastic flow) of p-y curve,

$$p = p_c(1.225\sqrt{A_s} - 0.75A_s - 0.411) \quad \text{..... (3.8)}$$

Above equation is valid for y greater than $18A_sy_{50}$ (Fig. 3.4).

The final p-y curve for stiff clay below water table is shown in Figure 3.4.

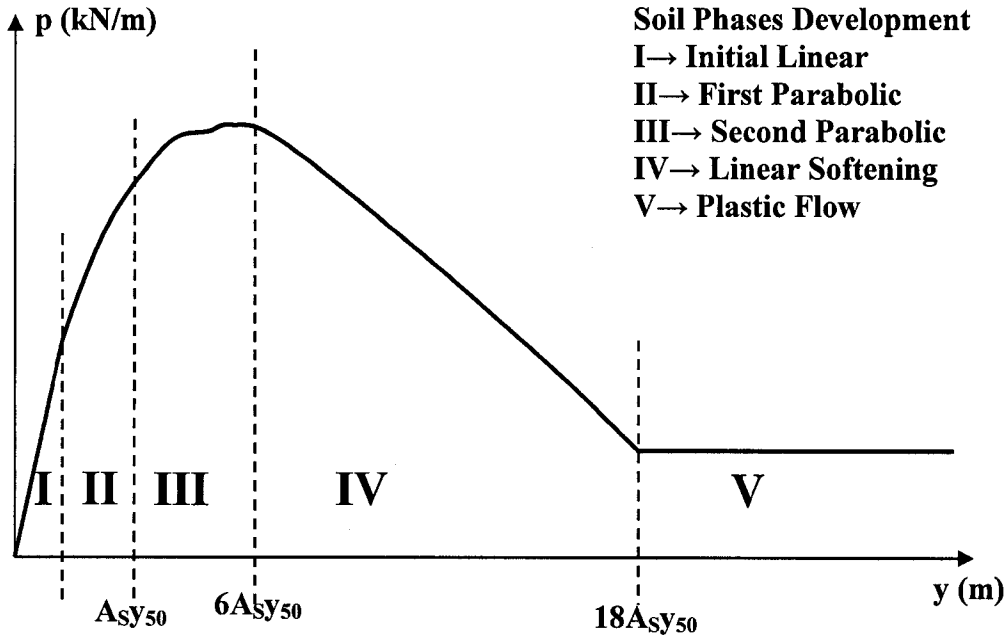


Fig. 3.4 The p-y curve for stiff clay below water table under static loading (Reese, 1975)

3.5 Laterally Loaded Pile Group

It is already discussed in Chapter 2 (literature review) that the best possible method to analyze the laterally loaded pile group, is by introducing the p-multiplier to the general p-y curve, by means of the following formula;

$$p_{gp} = f_m p_{sp} \quad \text{..... (3.9)}$$

where,

p_{gp} → p-value for the pile in group,

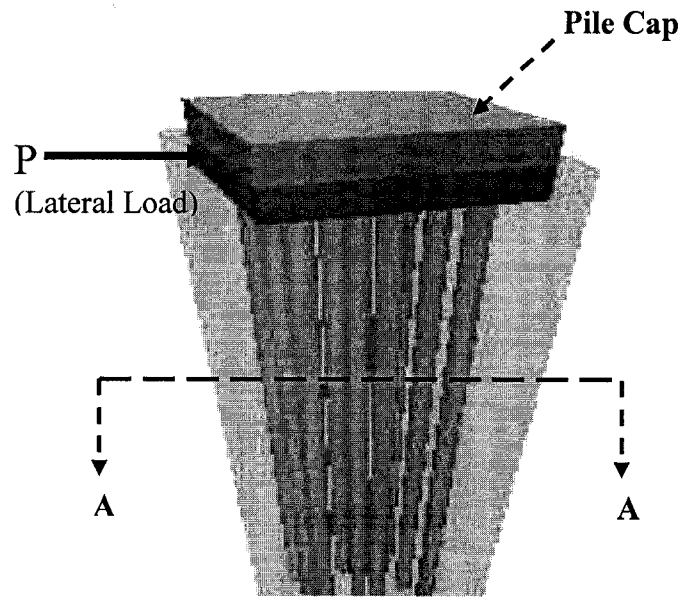
p_{sp} → p-value for single isolated pile, and

$f_m \rightarrow$ p-multiplier, obtained empirically from field tests on pile group.

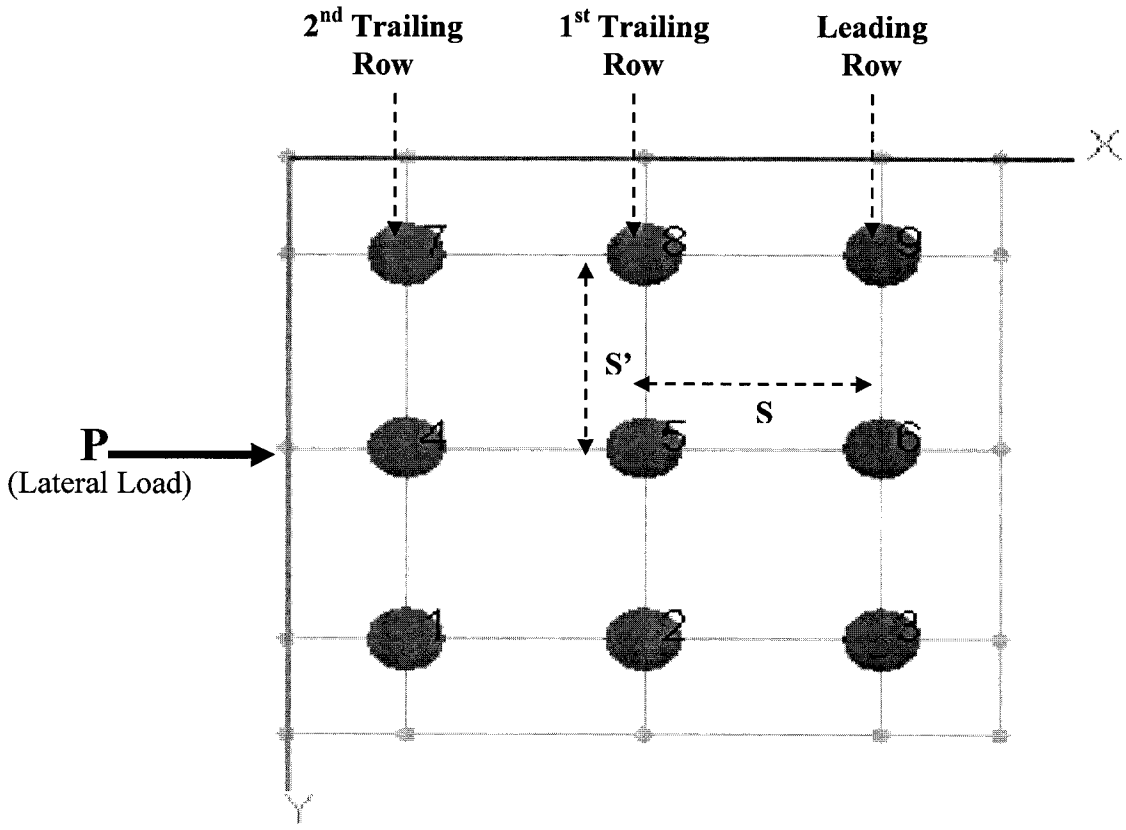
The usual design practice is to arrange piles in the direction of load (column) and perpendicular (rows) to the direction of load, but in the same plane as the plane of lateral load (as shown in Fig. 3.5).

Depending on the direction of the load, the rows are designated as leading row, first trailing row, second trailing row, and so on. As shown in figure 3.5(B), if the load is applied in direction from left to right, then the rightmost row in pile group is considered as leading row. All the researchers agreed on the conclusion that the leading row takes maximum load and it has the highest p-multiplier than the other rows. It is the general practice to apply same value of p-multiplier to all piles in same row. The rows following the leading row are marked as first trailing row, second trailing row, and so on. First trailing row has less capacity to bear load than the leading row and hence lower p-multiplier value. Same theory applies to other rows, as we go away from the leading row, the load bearing capacity of pile row decreases. Consequently, all rows behind the leading row are in the shadow of the leading row. The fact that the load carrying capacity of each trailing row is smaller than leading row is called 'shadowing effect'. Test by McVay et al. (1995) indicates that p-multiplier value for third, fourth, and subsequent trailing row is same.

The center to center spacing between two adjacent piles in a row in the direction of loading is indicated as **S** and that perpendicular to the direction of loading as $\mathbf{S}'$ (Figure 3.5B). Pile spacing is always given in reference to the pile diameter (D), such as, 3D, 4D. Many studies show that group effect gets negligible when **S** is equal to 6D and $\mathbf{S}'$ is equal to 3D.



(A) 3-D View of Pile Group (FB-MultiPier)



(B) Section A-A of Pile Group (3x3)

Fig. 3.5 General layout of piles in a pile group (3x3)

Mokwa & Duncan (2001) have assimilated the results of tests on pile group done by various researchers into tables, to get useful trends and similarities. One of the graphs from Mokwa & Duncan (2001) is shown in Figure 3.6 and the same graph will be useful in conducting this study.

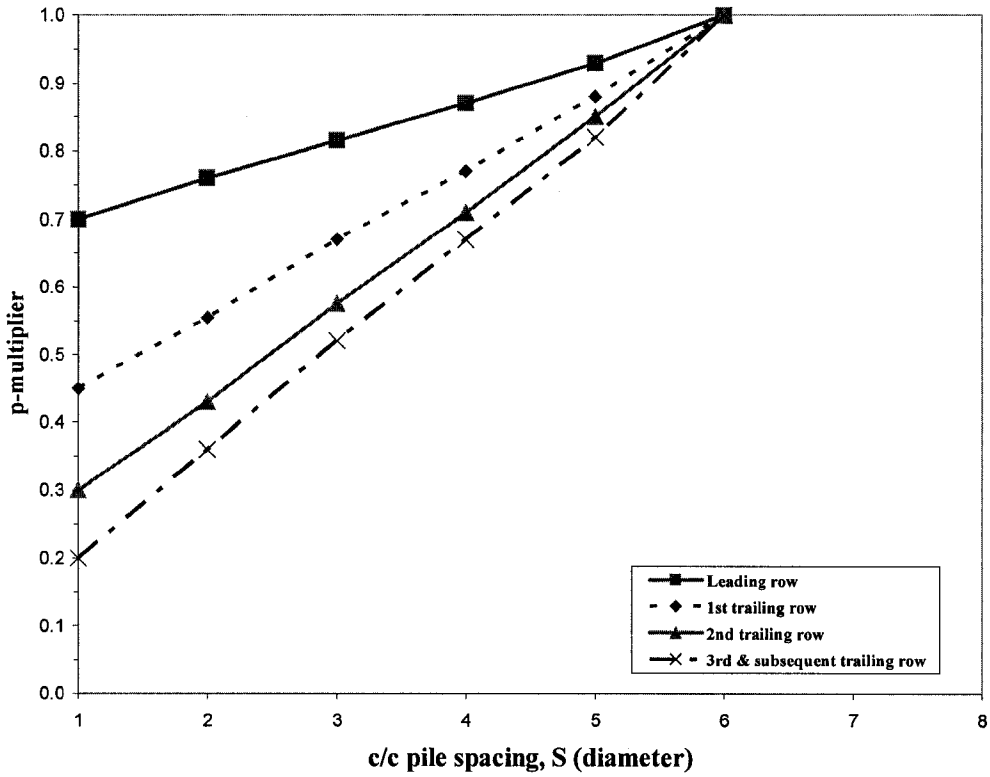


Fig. 3.6 Proposed p-multiplier design curves. (Mokwa & Duncan, 2001)

3.6 Uncertainties in Laterally Loaded Pile Model

Laterally loaded pile model includes the pile or pile group, soil, and lateral load. Like all the other geotechnical structures or models, laterally loaded pile model has also uncertainties connected with it. Generally, only those parameters whose uncertainty is expected to have an important effect on performance of pile system is considered for

probabilistic analysis. In probabilistic analysis, these parameters are expressed as random variables (For details; see Chapter 4).

There are two major uncertainties which affect the analysis of pile foundations:

- **Load uncertainties**: It is connected with all major type of loading such as wave, wind, earthquake, etc. The uncertainties enter through insufficient load record data, inaccuracies in the load transfer model. In details, it is explained elsewhere (Baecher et al. 1980; Tang 1981; Tang & Saadeghvaziri 1984).
- **Uncertainties about pile foundation response:** Analytical methods such as finite element analysis, finite difference method, etc. are generally used to visualize the performance of pile foundation. In this case, uncertainties arise because of uncertainty in soil profile, in the engineering properties of the pile material, and the analytical model used to predict the foundation response.

3.6.1 Uncertainties in pile

This includes uncertainties in **Pile stiffness (EI)** and **Pile diameter where soil reaction is acting (B).** The uncertainties in pile occur due to construction practices which deviate from the design, and the variations are unknown. For example caving of soil will modify the diameter of drilled piles and thus modify the pile stiffness. Improper vibration of concrete piles may result in unknown voids which reduces the pile stiffness. Corrosion of installed steel piles due to corrosive environment of surrounding soil.

3.6.2 Uncertainties in soil profile

Many studies were conducted to predict geotechnical variability (Spry et al. 1988; Kulhawy et al. 1992). The three main causes of uncertainty in soil profile modeling are natural heterogeneity or the in-situ variability of the soil, measurement error, and error in transformation model. First one occurs due to variation in mineral composition and stress history, varying depth of strata during soil formation, and fluctuations in moisture content and density of soil. Clearly, no amount of site exploration can supply sufficient information for a detailed deterministic description of the local variation at the site; only a probabilistic model can capture the important features with a minimum number of additional soil parameters. Second cause, measurement error, happens due to sample disturbance, test imperfections, and human factors. As shown in Fig. 3.7, in-situ measurements are also affected by limited availability of information about subsurface conditions. Soil profile characteristics must be judged from field or laboratory investigation of a limited number of soil samples. This is called statistical uncertainty and it can be decreased at the expanse of additional testing. The third source of uncertainty comes into play when empirical transformation model is used to get soil properties from the field or laboratory data.

The effect of above mentioned sources on the overall uncertainty in design soil property depends on site conditions, quality precautions on sampling procedure and equipment, and the accuracy of transformation model.

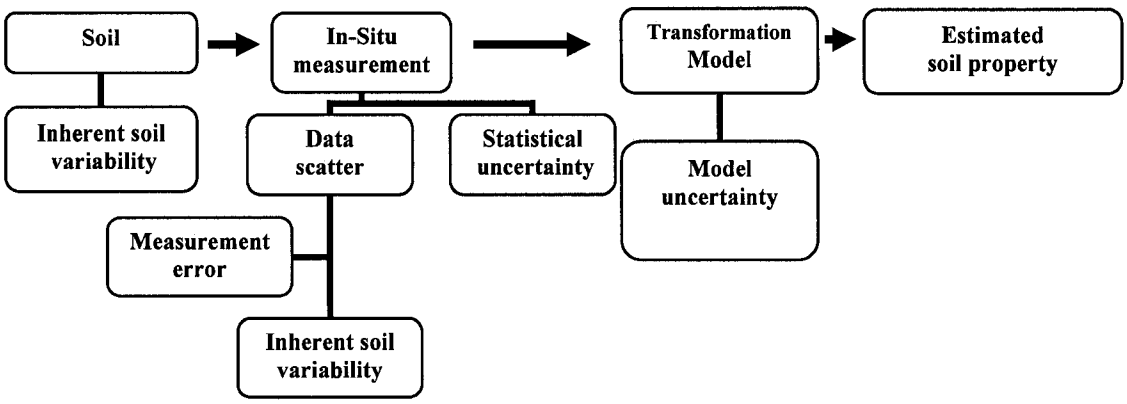


Fig. 3.7 Uncertainty in soil Property estimates (Kulhawy 1992)

The major parameters connected to soil profile includes following:

1. **Undrained shear strength (C):** When the pile cap is laid over the ground, sometimes it causes significant amount of frictional resistance between the pile cap and supporting soil, but it is often neglected in the design.
2. **Soil Modulus (k):** The method of installation of the pile (or the surrounding piles) will alter the stress state in the surrounding soil, and thus alter the soil strength (or soil modulus).
3. **Soil Unit Weight (γ):** Soil is a natural material and has been formed by a combination of various geologic, environmental, and physical-chemical processes. Many of these processes are continuing and can be modifying soil in situ. Also they cause non-homogeneity in soil, due to that the soil density varies horizontally as well as with depth.

4. **Half of failure strain (ε_{50}):** The stress-strain characteristics of two soils with the same ultimate strength may differ considerably, but these are usually assumed to be the same.
5. Laboratory test may not reflect the in-situ properties as a result of disturbance of soil samples tested.
6. Time related effects, such as creep or consolidation may occur, but these are not accounted for by current theories.

Even with best possible field and laboratory testing procedures there may be considerable uncertainty in predicting the appropriate variation in soil strength with depth, variation in pile material properties, and load variation. It is very hard if not impossible to conduct detailed deterministic evaluation; only a probabilistic model can capture all the variations.

CHAPTER 4

THEORY OF RELIABILITY

Uncertainty is omnipresent in geotechnical systems. When engineers face uncertainty, the conventional approach is to make conservative estimates of the design parameters and apply factor of safety to design. While, in reliability analysis, the uncertainties in design parameters are evaluated rationally by combining the appropriate component of uncertainties.

4.1 Random variables

In reliability analysis the variables which significantly influence the judgment of safety or failure, and which are characterized by substantial uncertainty are called **random variables.**

When we conduct an analysis on a structure, it gives us certain result. If we perform analysis **N** number of times on same structure with different outcome every time, then in probabilistic theory, each result from the analysis is known as **event** and all possible results form a **space** of **event**. Every event has some probability assigned to it. The function of event which fulfills certain conditions is known as random variable.

The uncertainties connected to the parameters of pile material (EI, B), soil surrounding the pile (C, ε_{50}, k, γ'), and applied load (lateral load P, Moment M) are

considered to be affecting the performance of pile up to greater extent. Therefore, these parameters are taken as random variables for probabilistic analysis.

4.1.1 Cumulative distribution and Probability density functions

In probabilistic analysis, random variables are represented by their cumulative distribution function and probability density function.

1. **Cumulative distribution function (CDF):** Suppose **X** is an random variable of discrete type or continuous type , then cumulative distribution function is given by,

$$F_X(x) = P\{X \leq x\}, \text{ where } -\infty \leq x \leq \infty \quad \text{..... (4.1)}$$

The value for CDF varies between 0 and 1. Example of a CDF for continuous random variable **X** is shown in Figure 4.1(a).

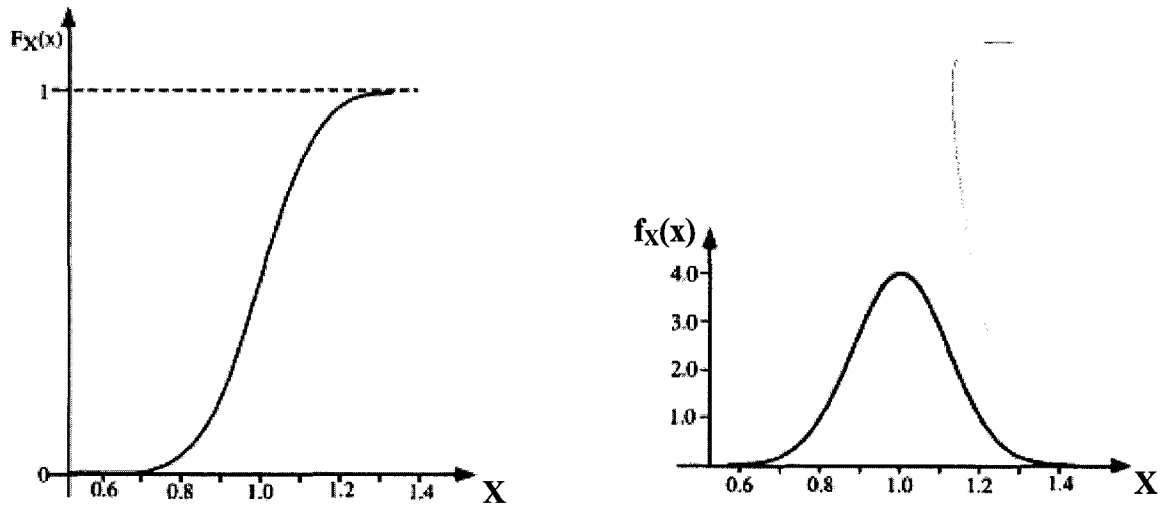
2. **Probability density function (PDF):** The first derivative of the cumulative density function is known as probability density function $f_X(x)$ of the continuous random variable **X**.

$$f_X(x) = \frac{dF_X(x)}{dx} \quad \text{..... (4.2)}$$

or,

$$F_X(x) = \int_{-\infty}^{x} f_X(u)du \quad \text{..... (4.3)}$$

We can also say that integration of PDF gives CDF. The example of PDF for the continuous random variable **X** is shown in Figure 4.1(b).



(A) Cumulative distribution function **(B) Probability density function**

Fig. 4.1 Representative of random variables

4.1.2 Statistical description of random variable

The properties of random variable can be described either graphically or analytically. Graphical presentation includes the frequency histograms. Analytical description can be given through following parameters:

1. **Mean Value (Expected Value) (X°):** The mean value of discrete random variable X is equal to the arithmetic mean of the test results (i.e. all the values of X).

$$X^{\circ} = \frac{1}{n}\sum_{i=1}^{n} Xi \quad \text{..... (4.4)}$$

Where, n→ number of results (or all values of X)

2. **Variance (Var X):** It measures the scattering of the discrete random variable (X) from the mean value (X°).

$$VarX = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - X^{\circ})^2 \quad \text{..... (4.5)}$$

3. **Standard Deviation (σ_X):** It is the positive square root of variance of X.

$$\sigma_X = \sqrt{VarX} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - X^{\circ})^2} \quad \text{..... (4.6)}$$

4. **Coefficient of variation (COV_X):** It is the ratio of standard deviation of discrete random variable X (σ_X) to mean value of X.

$$COV_X = \frac{\sigma_X}{X^{\circ}} \quad \text{..... (4.7)}$$

COV_x is a non-dimensional quantity.

5. **Covariance [$Cov(X_i,X_j)$]:** If more than one random variable is present, the definition of variance is extended to covariance. For the random variables X_i and X_j, covariance is given by,

$$Cov(X_i, X_j) = \frac{1}{n-1}\sum_{i,j=1}^{n}(X_i - X_i^{\circ})(X_j - X_j^{\circ}) \quad \text{..... (4.8)}$$

6. **Covariance matrix:** The variance and covariance for a set of random variables can be put into matrix form and is called covariance matrix.

$$[S_X]=\begin{bmatrix} Var(X_1) & Cov(X_1,X_2) & Cov(X_1,X_3) & \cdots & Cov(X_1,X_n) \\ Cov(X_2,X_1) & Var(X_2) & Cov(X_2,X_3) & \cdots & Cov(X_2,X_n) \\ \vdots & \vdots & & & \vdots \\ \vdots & \vdots & & & \vdots \\ Cov(X_n,X_1) & \cdots & \cdots & \cdots & Var(X_n) \end{bmatrix} \quad ..(4.9)$$

As, $$Cov(X_i,X_j)=Cov(X_j,X_i) \quad .....(4.10)$$

Covariance matrix is a symmetric matrix.

4.1.3 Types of random variables

The common types of random variables used in structural reliability analysis are:

- Uniform Random Variable
- Normal Random Variable
- Lognormal Random Variable
- Gamma Distribution
- Extreme Type III (Weibull Distribution)
- Poisson Distribution

For this study only normal random variable is needed and hence is discussed here in detail. All the other kinds of random variables are talked about in brief.

For uniform random variable, the PDF function has a constant value for all possible values of random variable within a certain range. The random variable X is lognormal random variable, if function of random variable Y = ln(X). A lognormal random variable is defined for positive values only. It is widely used in structural reliability analysis. The gamma distribution random variables are useful to characterize the probabilistic nature of the extreme values (largest or smallest values) of some

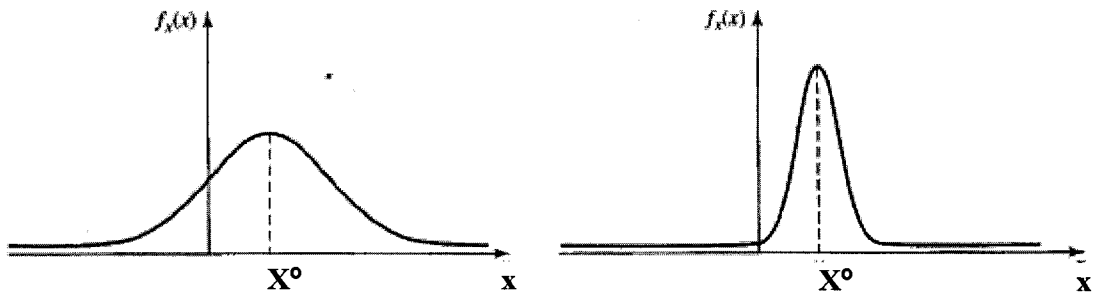
phenomenon over time. The Poisson distribution is a discrete probability distribution that can be used to calculate CDF for the number of occurrences of a particular event in a time or space interval (for example, the occurrence of the number of earthquakes within a certain time interval). For details on these random variables, refer "Probability, Random Variables and Stochastic Processes" by Papoulis and Unnikrishna Pillai (2002).

4.1.3.1 Normal Random Variable (Gaussian Distribution)

The normal distribution is one of the most important distributions in probability and statistics. If X is a random variable with mean value X° and standard deviation σ_X, then its PDF is given by:

$$f_X(x) = \frac{1}{\sigma_X \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{X - X^{\circ}}{\sigma_X} \right)^2 \right] \quad \text{..... (4.11)}$$

PDF for normal random variable has bell shaped curve with its symmetry around the mean value $\mathbf{X^{\circ}}$. The shape of the curve depends on the variance or standard deviation of X. The PDF curve of Fig. 4.2(a) has higher **Var(X)** than the PDF curve of Fig. 4.2(b). Therefore, as the **Var(X)** decreases the curve for PDF gets steeper and narrower.



(a) **(b)**

Fig. 4.2 Normal Random Variable

4.1.4 Statistical Linearization method

Let the function $f(\overline{X})$ describes the performance of pile structure (for example, pile head deflection) and it linearly depends on the vector of random design variables (related to pile material, soil, and lateral load) $\overline{X}$. Then, $f(\overline{X})$ is given by,

$$f(\overline{X}) = a_0 + a_1X_1 + a_2X_2 + ... + a_nX_n = a_0 + \sum_{i=1}^{n} a_iX_i \quad ..... (4.12)$$

where, a_0, a_1,.....,a_n are constants.

The mean value of function of random variable $f°(\overline{X})$, is given as,

$$f°(\overline{X}) = a_0 + \sum_{i=1}^{n} a_iX_i° \quad ..... (4.13)$$

Using Eq. 4.5, the variance for function of random variable $Var(f(\overline{X}))$ can be give by,

$$Var(f(\overline{X})) = E\left\langle \left(f(\overline{X}) - f°(\overline{X})\right)^2 \right\rangle$$

$$Var(f(\overline{X})) = E\left\langle f(\overline{X})^2 \right\rangle - \left(f°(\overline{X})\right)^2$$

Therefore,

$$Var(f(\overline{X})) = \sum_{i=1}^{n}\sum_{j=1}^{n} a_ia_jCov(X_i, X_j) \quad ..... (4.14)$$

If the n random variables are uncorrelated with each other,

$$Cov(X_i, X_j) = 0 \, for \, i \neq j \quad ..... (4.15)$$

Thus Eq. 4.14 simplifies to

$$Var(f(\overline{X})) = \sum_{i=1}^{n} a_i^2 Var(X_i) \quad ..... (4.16)$$

If there is more than one function of random design variable for the performance of pile structure (for example, pile head deflection and maximum bending moment in pile), then the number of functions can be expressed in matrix form,

$$\{f(\overline{X})\} = [C]\{\overline{X}\} \quad \text{..... (4.17)}$$

where, [C] is a matrix of order mxn with real elements.

And,

$$\{f(\overline{X})\}^T = \{f_1(\overline{X}), f_2(\overline{X}), f_3(\overline{X}), ..., f_n(\overline{X})\} \quad \text{..... (4.18)}$$

$$\overline{X}^T = \{X_1, X_2, X_3, ..., X_n\} \quad \text{..... (4.19)}$$

$$\overline{X^\circ}^T = \{X_1^\circ, X_2^\circ, X_3^\circ, ..., X_n^\circ\} \quad \text{..... (4.20)}$$

$$\begin{Bmatrix} f_1(\overline{X}) \\ f_2(\overline{X}) \\ \vdots \\ f_m(\overline{X}) \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ C_{m1} & \cdots & \cdots & C_{mn} \end{bmatrix} \begin{Bmatrix} X_1 \\ X_2 \\ \vdots \\ \vdots \\ X_n \end{Bmatrix} \quad \text{..... (4.21)}$$

This means that arbitrary component of function $\{f(\overline{X})\}$ can be determined as;

$$f_k = \sum_{i=1}^{n} C_{ki} X_i \quad \text{..... (4.22)}$$

Mean value of function of random variable,

$$f_k^\circ = \sum_{i=1}^{n} C_{ki} X_i^\circ \quad \text{..... (4.23)}$$

Same way the second arbitrary component can be given as,

$$f_l = \sum_{j=1}^{n} C_{lj} X_j \quad \text{.....,,,,.. (4.24)}$$

Then $Cov(f_k, f_l)$ is given as;

$$Cov(f_k, f_l) = E\langle (f_k - f_k^\circ)(f_l - f_l^\circ) \rangle$$

$$Cov(f_k, f_l) = E\left\langle \left(\sum_{i=1}^{n} C_{ki} X_i - \sum_{i=1}^{n} C_{ki} X_i^\circ \right) \left(\sum_{j=1}^{n} C_{lj} X_j - \sum_{j=1}^{n} C_{lj} X_j^\circ \right) \right\rangle$$

$$Cov(f_k, f_l) = \sum_{i=1}^{n} C_{ki} \sum_{j=1}^{n} C_{lj} E\langle (X_i - X_i^\circ)(X_j - X_j^\circ) \rangle \quad \text{..... (4.25)}$$

It can also be written as;

$$\left[S_{f(\bar{X})}\right] = [C][S_X][C]^T \quad \text{..... (4.26)}$$

where, $\left[S_{f(\bar{X})}\right]$ is an covariance matrix for the function of random variables and $[S_X]$ is the covariance matrix for random variables.

If n design random variables are independent to each other then,

$$Cov(X_i, X_j) = 0 \, for \, i \neq j$$

That means covariance matrix for random variable $\bar{X}$ will be,

$$[S_X] = \begin{bmatrix} VarX_1 & 0 & \cdots & \cdots & 0 \\ 0 & VarX_2 & \cdots & \cdots & 0 \\ \vdots & \vdots & \ddots & & \vdots \\ 0 & \vdots & & \ddots & 0 \\ 0 & 0 & \cdots & 0 & VarX_n \end{bmatrix} \quad \text{..... (4.27)}$$

All these values are valid regardless of the PDF of the random variables.

Instead of linear function, suppose function $f(\overline{X})$ is a non-linear function of random variables $\overline{X}$. The expansion of the function in Taylor series in the vicinity of mean value of $\overline{X}$ gives,

$$f(\overline{X}) \approx f(\overline{X}^{\circ}) + \sum_{i=1}^{n} (X_i - X_i^{\circ}) \frac{\partial f(\overline{X})}{\partial X_i}\Big|_{Evaluated\_at\_\overline{X}^{\circ}} \quad \ldots\ldots\ldots\ldots (4.28)$$

Suppose more than one number of functions of random variables are present. Then, the above equation is given as;

$$\{\overline{f}(\overline{X})\} \approx \{\overline{f}(\overline{X}^{\circ})\} + \left[\frac{\partial \overline{f}(\overline{X}^{\circ})}{\partial X_i}\right]\{X_i - X_i^{\circ}\} \quad \ldots\ldots\ldots\ldots\ldots (4.29)$$

Where, $\left[\frac{\partial \overline{f}(\overline{X}^{\circ})}{\partial X_i}\right]$ is a structural sensitivity matrix and is given as;

$$\left[\frac{\partial \overline{f}(\overline{X}^{\circ})}{\partial X_i}\right] = \begin{bmatrix} \frac{\partial f_1(\overline{X}^{\circ})}{\partial X_1} & \frac{\partial f_1(\overline{X}^{\circ})}{\partial X_2} & \ldots\ldots & \ldots\ldots & \frac{\partial f_1(\overline{X}^{\circ})}{\partial X_n} \\ \frac{\partial f_2(\overline{X}^{\circ})}{\partial X_1} & \frac{\partial f_2(\overline{X}^{\circ})}{\partial X_2} & \ldots\ldots & \ldots\ldots & \frac{\partial f_2(\overline{X}^{\circ})}{\partial X_n} \\ \vdots & \vdots & \ddots & & \vdots \\ \vdots & \vdots & & \ddots & \vdots \\ \frac{\partial f_n(\overline{X}^{\circ})}{\partial X_1} & \frac{\partial f_n(\overline{X}^{\circ})}{\partial X_2} & \ldots\ldots & \ldots\ldots & \frac{\partial f_n(\overline{X}^{\circ})}{\partial X_n} \end{bmatrix} \quad \ldots\ldots\ldots (4.30)$$

The $\{\overline{f}(\overline{X})\}$, $\overline{X}$, and $\overline{X}^{\circ}$ are same as given in Eq.4.18, 4.19, and 4.20.

And covariance matrix of the functions of random variable is given by,

$$[S_f] = \left[\frac{\partial f(\overline{X}^{\circ})}{\partial X_i}\right][S_X]\left[\frac{\partial f(\overline{X}^{\circ})}{\partial X_i}\right]^T \quad \text{..... (4.31)}$$

Where $[S_f]$ is an covariance matrix for function and $[S_X]$ is an covariance matrix for random variable. Both $[S_f]$ and $[S_X]$ are symmetric matrix.

4.2 Limit States and Limit State Functions

Limit states are used to help define failure in the perspective of structural reliability analyses. They define the situation when structure cannot perform its intended function. Limit states are of three types: Ultimate, Serviceability, and Fatigue limit state. Ultimate limit states are usually the prime concern for the engineers because it is connected to the load carrying capacity of structure. Example includes the moment carrying capacity (M_{max}), crushing strength, etc. Serviceability limit states are more related to the operational equipment for offshore platform than the structural safety. It includes excessive deflection, vibration, and cracks in structure. As from the name itself, fatigue limit states are related to the damage in structure due to fatigue. Fatigue occurs due to repeated loading on the structure. Examples include the occurrence of waves produced by wind acting on offshore structures, vehicle passing again and again through bridge, wind load acting on high-rise buildings, retaining walls, etc; also temperature changes.

In this study we will check the laterally loaded pile and pile group for ultimate limit states (maximum bending moment of pile, M_{max}) and serviceability limit states (pile head deflection, Y_{top}) in the framework of reliability analysis.

Reliability analysis undertakes the check through **limit state function**. Suppose the maximum capacity or resistance of pile structure is denoted by f^{Resist} and the lateral load effect on pile structure is denoted as $f^{Current}$, then limit state function or margin of safety (g(f)) is given as,

$$g(f) = f^{Resist} - f^{Current} \quad \text{..... (4.32)}$$

where, f^{Resist} is the function of pile resistance and has mean value $\left(f^{Resist}\right)$ and standard deviation $\sigma_{f^{Resistx}}$ or variance $Var\left(f^{Resist}\right)$.

The value of $\left(f^{Resist}\right)$ and $Var\left(f^{Resist}\right)$ is not dependent on the analysis of laterally loaded pile for soil-structure interaction and its value is directly available from the literature and standard codes. On the contrary to that the $f^{Current}$ is a function of random design variable such as elastic stiffness and diameter of pile, cohesion, strength and density of soil and its mean, standard deviation, and COV is obtained from the soil-structure interaction analysis of pile. These two functions f^{Resist} and $f^{Current}$ are related to the performance of pile structure. If $f^{Resist} > f^{Current}$, pile structure is safe else it fails. The probability of failure of pile structure is:

$$P_f = P(f^{Resist} - f^{Current} < 0) = P(g(f) < 0) \quad \text{..... (4.33)}$$

For example, pile head deflection (Y_{Top}) is connected to the serviceability of pile structure. Therefore, for this specific case, f^{Resist} is given as Y_{Top}^{Resist}, same way $f^{Current}$ is given as $Y_{Top}^{Current}$ and limit state function $g(f)$ is given as $g(Y_{Top})$. The schematic diagram for normal PDF of Y_{Top}^{Resist}, $Y_{Top}^{Current}$ and $g(Y_{Top})$ is shown in Fig. 4.3.

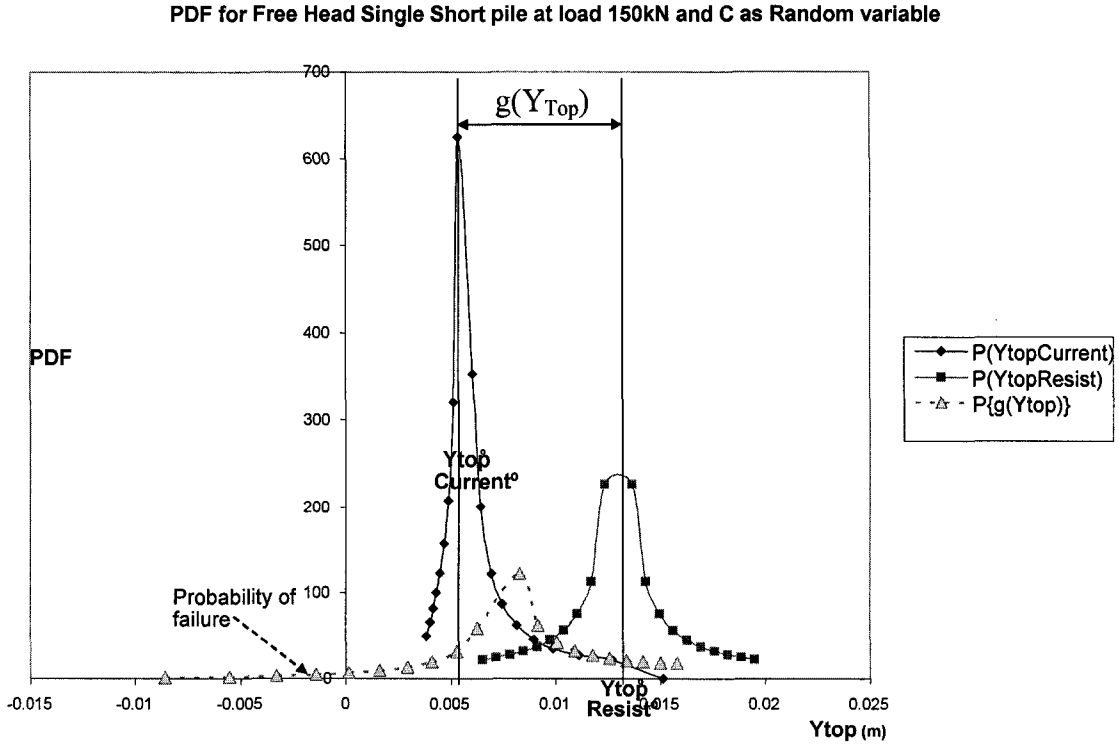


Fig. 4.3 PDF's for Y_{Top} Current, Resist, and $g(Y_{Top})$.

As g(f) is the function of f^{Resist} and $f^{Current}$, practically it is very hard, if not impossible, to calculate joint disrtribution function for random variables. Therefore, computation of probability of failure of a structure is very cumbersome when random variables are associated with it. Other way to check structural safety is by **reliability index.**

4.2.1 First-Order Second-Moment Reliability Index

This method is developed by Cornell in 1969. He gave the name to this method as "First-Order Second-Moment Reliability Method" because it is based on the first-order Taylor series approximation of the limit state function and uses only second moments statistics i.e. mean and variance (or covariance) of the functions of random variables. The

mean is intended to be a best estimate without conservatism, while the variance or standard deviation is used to represent the uncertainty. The function is given as:

$$g(f) = f^{Resist} - f^{Current} \quad \text{..... (4.34)}$$

where mean and variance of $g(f)$ is,

$$(g(f))^{\circ} = (f^{Resist})^{\circ} - (f^{Current})^{\circ} \quad \text{..... (4.35)}$$

and,

$$Var(g(f)) = Var(f^{Resist}) + Var(f^{Current}) \quad \text{..... (4.36)}$$

or,

$$\sigma^2_{g(f)} = \sigma^2_{f^{Resist}} + \sigma^2_{f^{Current}} \quad \text{..... (4.37)}$$

The probability of failure is given by,

$$P_f = P(f^{Resist} - f^{Current} < 0) = P(g(f) < 0) = \Phi\left(-\frac{(g(f))^{\circ}}{\sigma_{g(f)}}\right) \quad \text{..... (4.38)}$$

$$P_f = 1 - \Phi\left(\frac{(f^{Resist})^{\circ} - (f^{Current})^{\circ}}{\sqrt{\sigma^2_{f^{Resist}} + \sigma^2_{f^{Current}}}}\right) \quad \text{..... (4.39)}$$

where Φ is the cumulative distribution function for a function of standard normal variable and the ratio of mean to the standard deviation of $g(f)$ is known as **reliability index.**

$$\beta = \left(\frac{(g(f))^{\circ}}{\sigma_{g(f)}}\right) \quad \text{..... (4.40)}$$

or,

$$\beta = \left(\frac{(f^{Resist})^{\circ} - (f^{Current})^{\circ}}{\sqrt{\sigma^2_{f^{Resist}} + \sigma^2_{f^{Current}}}}\right) \quad \text{..... (4.41)}$$

The reliability index connected to serviceability of pile (pile head deflection, Y_{Top}) β_{Ytop} is schematically shown in Figure 4.4.

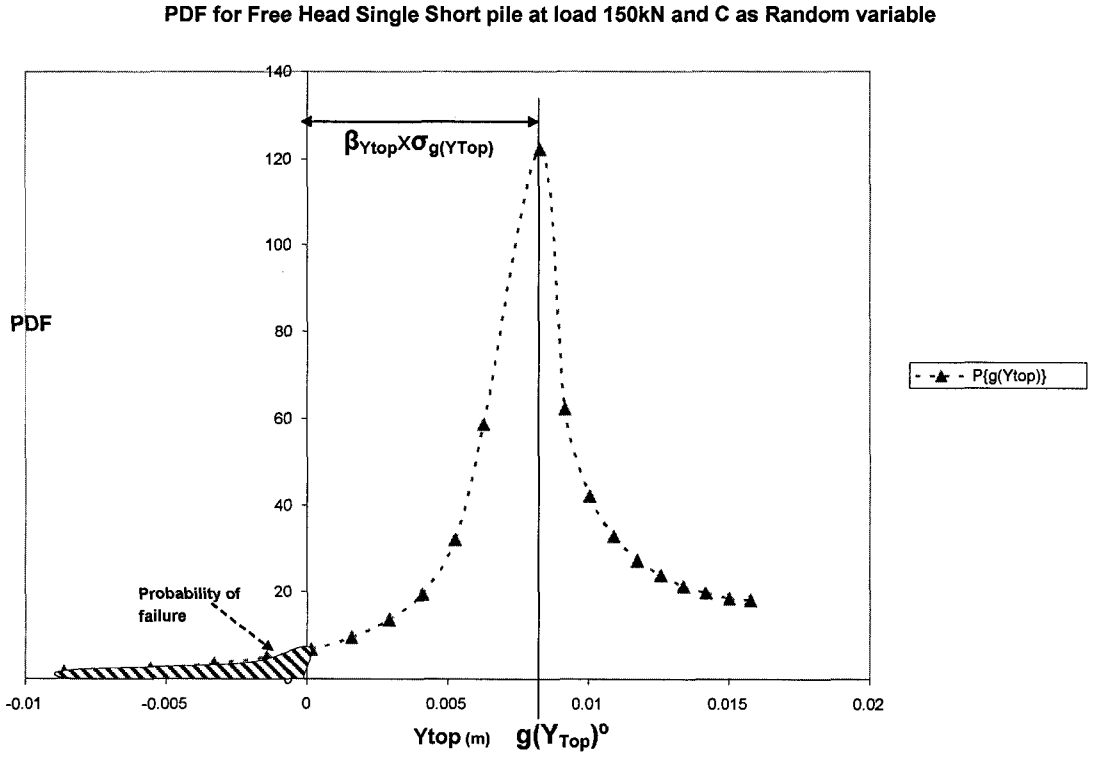


Fig. 4.4 Graphical representation of reliability index β_{Ytop}

These above formulation may be generalized to N number of function of random design variables. Let the limit state function be given as

$$g(\overline{f}) = g(f_1, f_2, f_3, ..., f_n) \quad \text{..... (4.42)}$$

A Taylor series expansion of the limit state function about the mean values gives,

$$g(\overline{f}) = g(\overline{f^{\circ}}) + \sum_{i=1}^{n} \frac{\partial g}{\partial f_i}(f_i - f_i^{\circ})\Big|_{evaluated\_at\_the\_mean\_values} \quad \text{..... (4.43)}$$

The first-order approximate mean and variance is given by,

$$\left(g(\overline{f})\right)^{\circ} = g(f_1^{\circ}, f_2^{\circ}, ..., f_n^{\circ}) \quad \text{..... (4.44)}$$

and,

$$Var(g(f)) = \sigma_{g(f)}^2 \approx \sum_{i,j=1}^{n} \frac{\partial g}{\partial f_i} \frac{\partial g}{\partial f_j} Cov(f_i, f_j) \quad \text{..... (4.45)}$$

If the variables are statistically independent, then the variance become,

$$Var(g(f)) = \sigma_{g(f)}^2 \approx \sum_{i=1}^{n} \left(\frac{\partial g}{\partial f_i} \right)^2 Var(f_i) \quad \text{..... (4.46)}$$

No codified requirements are available for the reliability index in an ultimate limit states but Nordic Committee on Building Regulation (NKB)(1978) have suggested some values, given in Table 4.1. For serviceability limit states NKB suggested a reliability index greater than 1to2 for a one year period.

Table 4.1 Reliability indices (failure probabilities) connected to ultimate strength for a 1 year reference period (Madsen et al. 1995)

Failure Type Consequences	Ductile with reserve capacity	Ductile	Brittle
Less serious	3.1 (10^{-3})	3.7 (10^{-4})	4.2 (10^{-5})
Serious	3.7 (10^{-4})	4.2 (10^{-5})	4.7 (10^{-6})
Very serious	4.2 (10^{-5})	4.7 (10^{-6})	5.2 (10^{-7})

CHAPTER 5

NUMERICAL ANALYSIS OF LATERALLY LOADED PILES

The goal of this study is to perform the statistical analysis of laterally loaded single isolated pile and pile group embedded in stiff clay below water table. Statistical analysis performs the usual procedure of checking the structure for ultimate and serviceability limit states, through probabilistic modeling and reliability method. Like the other geotechnical structures, laterally loaded piles also have some uncertainties connected with it which affect the performance of structure. If small changes in the parameters connected to uncertainty results in the large changes in the performance of the structure, then those parameters should be taken into consideration through probabilistic modeling.

In the previous chapters, we talked about the theoretical basis of probabilistic modeling and reliability method. In this chapter we will use those basics to conduct our statistical analysis on laterally loaded piles.

5.1 Major random design variables in laterally loaded pile

We already discussed in Chapter 3 that the major parameters affecting the performance of laterally loaded piles are connected with the pile itself, the soil surrounding the pile, and the lateral load applied at the head of the pile. Before conducting this analysis available literature has been examined to find out what are the

major parameters connected to pile, surrounding soil, and lateral load, whose uncertainty affects the performance of pile structure. These parameters are then taken as random variables to conduct probabilistic modeling and reliability analysis.

5.1.1 Random design variables connected to pile

For this study a round hollow structural section of ASTM A500 grade C is used with following properties:

- Designation: HSS 508 x 13- Round
- Outside Diameter: 0.508 m
- Wall Thickness: 0.01143 m
- Area: 0.0178 m^2
- Moment of Inertia (I_x=I_y): 5.5x10^{-4} m^4
- Young's Modulus (E): 200 GPa
- Torsional Inertia (J):1100x10^6 mm^4
- Unit Weight: 1.52 kN/m
- Allowable stresses (Fy): 317 MPa
- Yield Moment (M_R): 684.7 kN.m
- Plastic Moment: 894 kN.m

The major random variables connected to the pile include:

1. **Diameter of pile (B)** with the mean value **(B^o)** 0.508 mm.
2. **Elastic Stiffness of pile (EI)** with the mean value **(EI^o)** 110x10^3 kN.m^2

5.1.2 Major random variables connected to the soil

For this study, the soil around the pile is stiff clay below water table. The major design random variables related to the soil are:

1. **Undrained shear strength (Cohesion) (C)** with the mean value **(C^o)** 75 kPa
2. **Soil Modulus (k)** with the mean value **(k^o)** 136000 kPa/m
3. **Half of failure strain (ε_{50})** with the mean value **($\varepsilon_{50}{}^o$)** 0.007
4. **Submerged Unit Weight (γ'):** As the soil is below water table, we have to consider submerged unit weight.

$$(\gamma')^o = \gamma - \gamma_w = 15.71 - 9.81 = 5.9 kN/m^3 \quad \text{..... (5.1)}$$

All the above values for soil design parameters are taken from the manual of program COM624, as recommended by authors of p-y models.

5.2 Functions of design random variables

The purpose of the reliability analysis is to investigate the safety of laterally loaded pile structure against ultimate limit state failure and serviceability failure. This study will examine the pile structure for maximum bending moment i.e. $\mathbf{M_{Max}}$ (Ultimate limit state) and pile head deflection i.e. $\mathbf{Y_{TOP}}$ (Serviceability limit state). For the reliability analysis, $\mathbf{M_{Max}}$ and $\mathbf{Y_{TOP}}$ are considered as a vector of functions of design random variables (B, EI, C, k, γ',ε_{50}).

Vector of random design variables $\overline{X}$,

$$\{X\}^T = \{B, EI, C, \varepsilon_{50}, k, \gamma'\} \quad \text{..... (5.2)}$$

Vector of function of random design variable,

$$\{f(\overline{X})\}^T = \{M_{Max}, Y_{Top}\} \quad \text{..... (5.3)}$$

5.3 Relative stiffness factor

Relative stiffness factor was formulated by Reese & Matlock (1956) and as the name indicates, it shows the relation between the stiffness of soil and the flexural stiffness of the pile. It is denoted by capital letter **T.**

For the analysis, it is important to know the failure mechanism of piles. Long pile fails with the formation of the plastic hinge and the short pile fails with extreme rotation (free head) or translation (fixed head). **T** is the deciding factor for long or short pile. If the length of the pile is more than 5**T**, then pile is considered as long pile. If the length of pile is less than 4**T**, then pile comes in short pile category.

For free or fixed head loading, T is given by

$$T = \sqrt[3]{\frac{y_t EI}{A_y H_t}} \quad \text{..... (5.4)}$$

where,

A_y=2.43 for free head pile

and,

A_y=0.93 for fixed head pile.

Y_t = deflection of the pile at the ground line.

H_t = horizontal load applied at the ground line.

Values of y_t and H_t were obtained from the formulation prepared by Evans & Duncan (1982), called Characteristic Load and Moment method. This method includes following steps:

1. Calculate the Characteristic Shear Load (H_c)

$$H_C = \lambda B^2 E R_I \left(\frac{\sigma_p}{E R_I}\right)^m (\varepsilon_{50})^n \quad \text{..... (5.5)}$$

where,

$\lambda \rightarrow$Dimensionless parameter =1.0 (for plastic clay and sand)

$= (0.14)^n$ (for brittle clay such as stiff clay)

B $\rightarrow$ Diameter of pile

E $\rightarrow$ Young's modulus for pile material

$R_I \rightarrow$Dimensionless relative moment of inertia of the pile section

$$R_I = \frac{I}{\pi B^4 / 64} \quad \text{..... (5.6)}$$

I $\rightarrow$ Moment of inertia of the pile

$\sigma_p \rightarrow$ Passive pressure

For cohesive soil, $\sigma_p = 4.2S_u$

Su $\rightarrow$ (Cu) Undrained shear strength

$\varepsilon_{50} \rightarrow$ Strain at which half of the strength of the clay is mobilized

m $\rightarrow$ passive pressure exponent = 0.683 for cohesive soil

n $\rightarrow$ strain exponent = -0.22 for cohesive soil

2. From Figure 5.1 or 5.2, assume the value of y_t/B and get the value of y_t.
3. By using Figure 5.1or 5.2, get the value of H_t/H_c and calculate H_t.
4. Put the value of y_t and H_t into the formula for **T**.

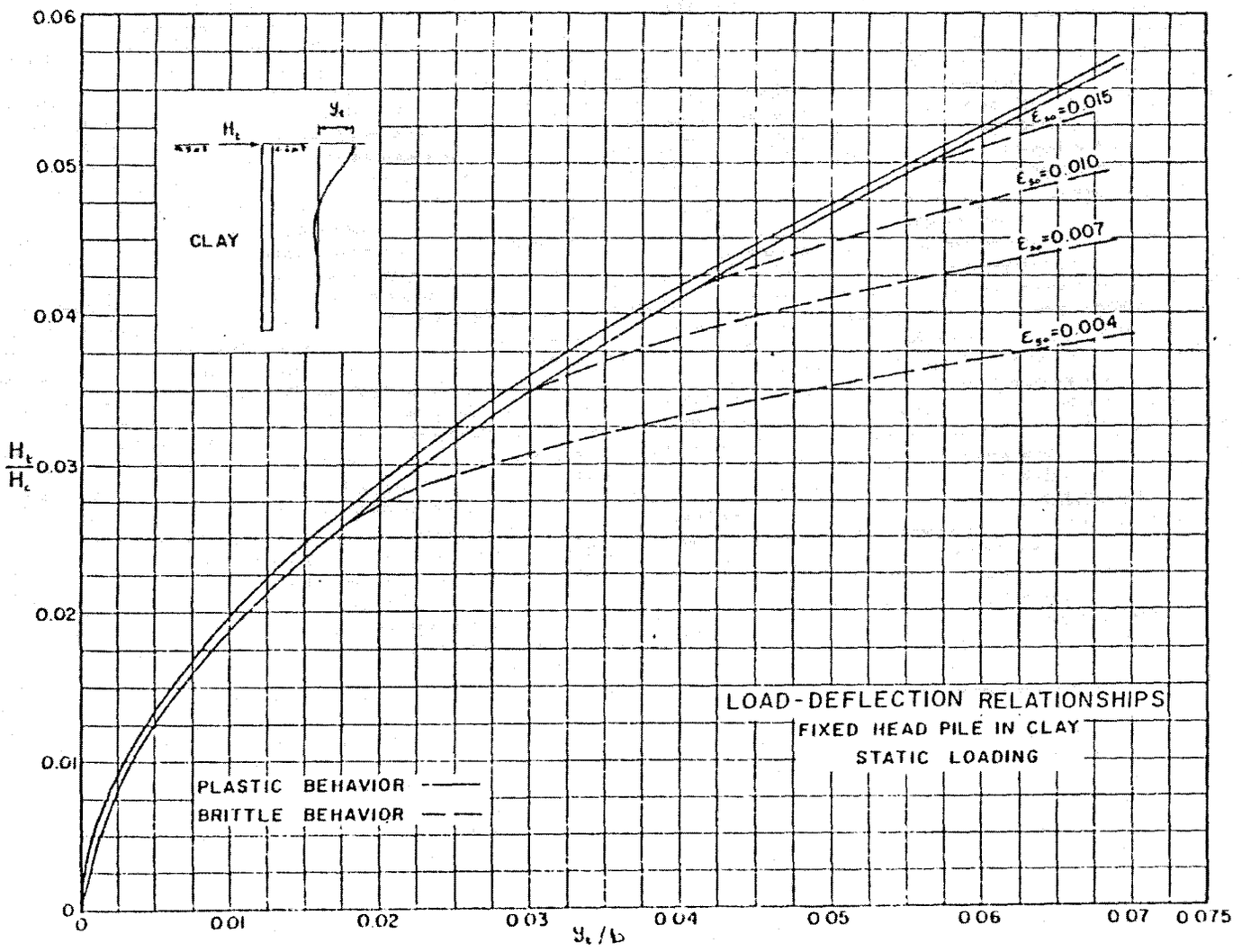


Fig. 5.1 Load-Deformation Curves for Free Head Pile in Clay-Static (Evans and Duncan, 1982)

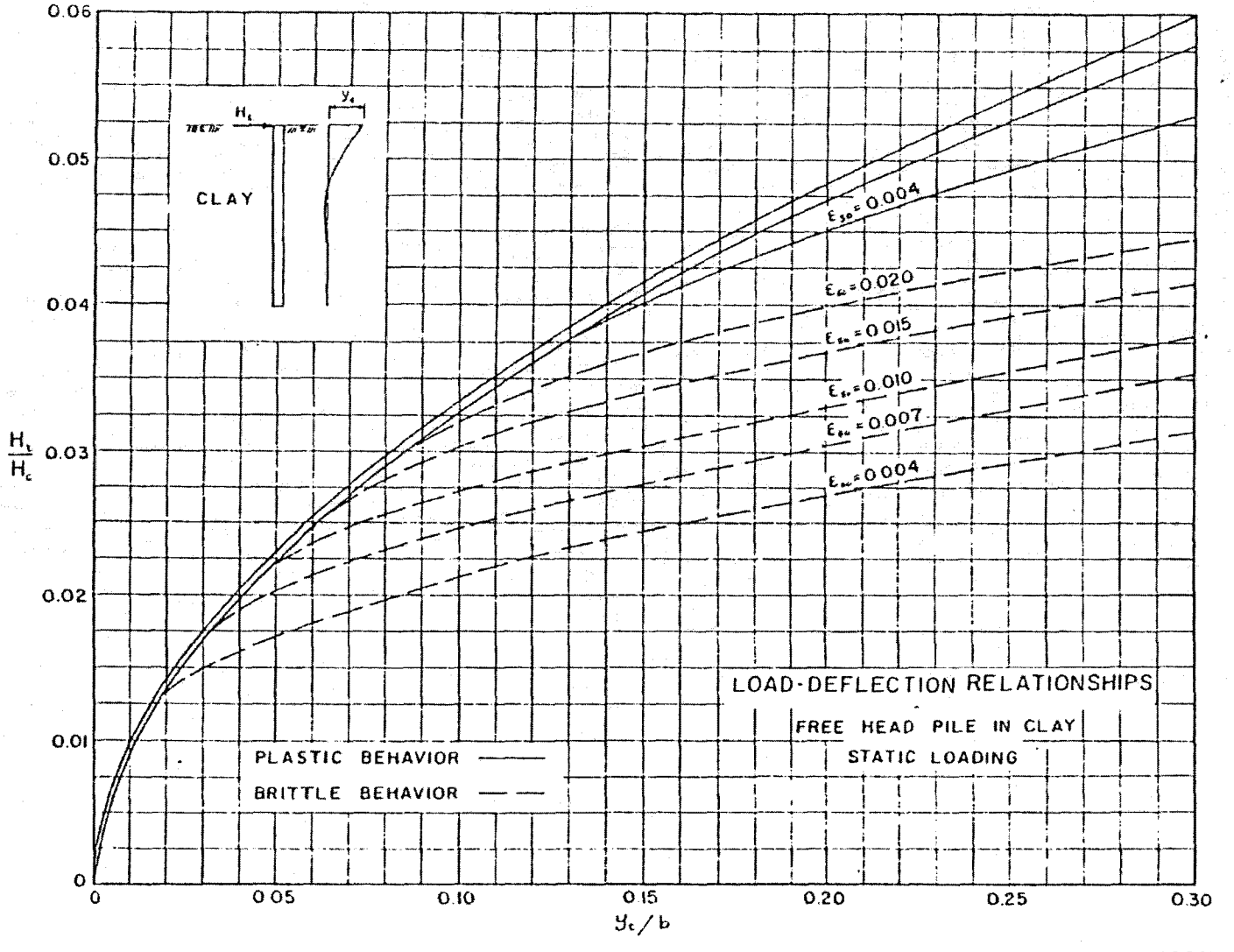


Fig. 5.2 Load-Deformation curves for fixed head pile in clay-static loading (Evans and Duncan, 1982)

Sample calculation for T

In our case,

B = 0.508 m

I = 0.00055 m^4

ε_{50} = 0.007 (for stiff clay)

E = 200 GPa

$S_u = C_u$ = 75 kPa

Case I: Free Head Pile

$$Hc = \lambda B^2 E R_I \left(\frac{\sigma_p}{E R_I}\right)^m (\varepsilon_{50})^n \quad \text{..... (5.7)}$$

$$\lambda = (0.14)^n = (0.14)^{-0.22} = 1.541 \quad \text{..... (5.8)}$$

$$R_I = \frac{I}{\pi B^4/64} = \frac{0.00055}{\pi(0.508)^4/64} = 0.168 \quad \text{..... (5.9)}$$

$\sigma_p = 4.2S_u = 4.2x75 = 315$ kPa..... (5.10)

Therefore,

$$H_c = 1.541(0.508)^2(200*10^6)(0.168)\left(\frac{315}{(200*10^6)(0.168)}\right)^{0.683}(0.007)^{-0.22} \quad \text{.. (5.11)}$$

$$H_c = 14648.87kN \quad \text{..... (5.12)}$$

From Figure 5.1,

Assume value of $y_t / B = 0.15 \Rightarrow y_t = 0.076m$ ..... (5.13)

$$\therefore H_t / H_c = 0.0275 \quad \text{..... (5.14)}$$

$$\Rightarrow H_t = 0.0275 * H_c$$

$$\Rightarrow H_t = 402.84kN \quad \text{..... (5.15)}$$

Now, Eq.5.4 can be written as,

$$T = \sqrt[3]{\frac{y_t EI}{A_y H_t}}$$

$$\Rightarrow T = \sqrt[3]{\frac{0.076 * 200 * 10^6 * 0.00055}{2.43 * 402.84}} \quad \ldots\ldots (5.16)$$

$$\Rightarrow T = 2.05m \quad \ldots\ldots (5.17)$$

Case II Fixed head pile

H_c is same as the Case I, i.e. H_c=14648.87 kN

From Figure 5.2, assume value of $y_t / B = 0.035 \Rightarrow y_t = 0.01778m$ ..... (5.18)

$$\therefore H_t / H_c = 0.037 \quad \ldots\ldots (5.19)$$

$$\Rightarrow H_t = 0.037 * H_c$$

$$\Rightarrow H_t = 542kN \quad \ldots\ldots (5.20)$$

$$\therefore T = \sqrt[3]{\frac{y_t EI}{A_y H_t}}$$

$$\Rightarrow T = \sqrt[3]{\frac{0.01778 * 200 * 10^6 * 0.00055}{0.93 * 542}} \quad \ldots\ldots (5.21)$$

$$\Rightarrow T = 1.57m \quad \ldots\ldots (5.22)$$

This study will be conducted on single short pile, single long pile, and long pile group.Details about the lengths are given in Table 5.1.

Table 5.1 Length of piles used for analysis

	Single Pile				Pile Group (3D, 4D, 5D)	
	Short Pile		Long Pile		Long Pile	
	Free Head	Fixed Head	Free Head	Fixed Head	Hinged Head	Fixed Head
Length	3T	3T	10T	10T	10T	10T
T (m)	2.05	1.57	2.05	1.57	2.05	1.57
Length (m)	6.15	4.71	20.5	15.7	20.5	15.7

5.4 The p-y curve for stiff clay below water table

Procedure to compute p-y for stiff clay below water table is given in Chapter 3. Computer programs such as COM624P (Federal Highway Administration, 1993) and FB-MultiPier (Florida Bridge Software Institute, 2000) use the p-y curve for stiff clay below water table formulated by Reese et al. (1975). Example of p-y curve used in this study, obtained from COM624P, is shown in Figure 5.3.

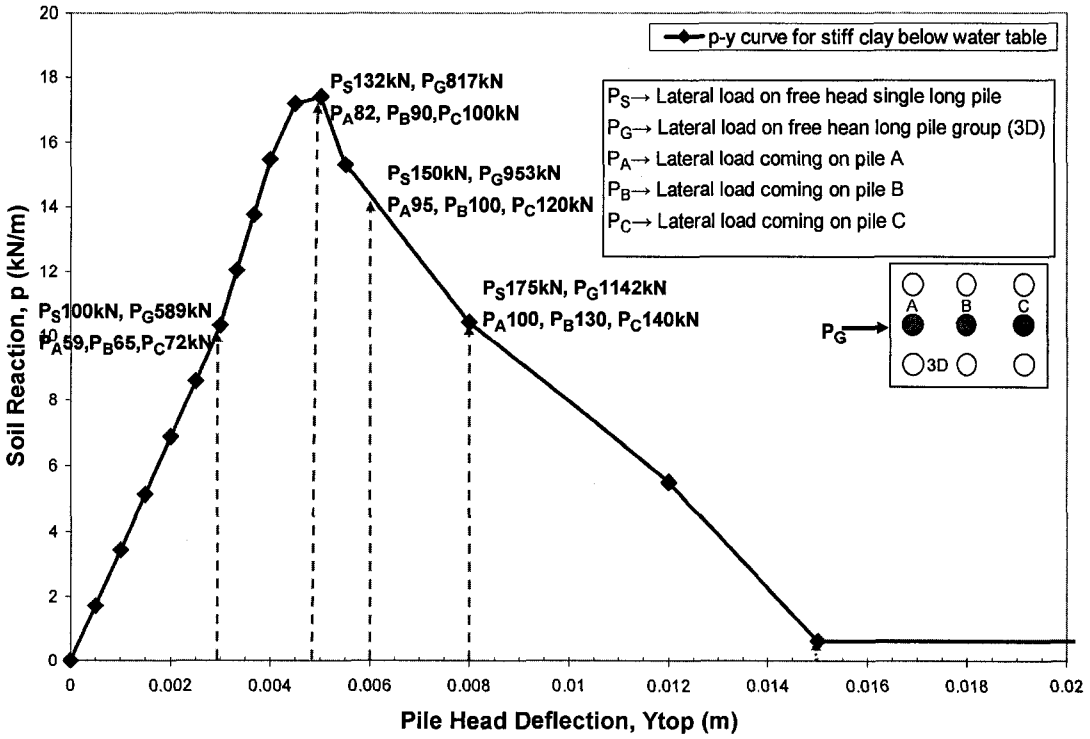


Fig. 5.3 The p-y curve for stiff clay below water table (Reese et al. 1975) at 1 inch below ground line (Specific to this study)

5.5 Structural Analysis of Single Pile

Program **COM624P Version 2.0** is used for structural analysis of single isolated pile. The earliest version was developed by S. T. Wang and L. C. Reese (1989) under the sponsorship of Federal Highway Administration. The program is based on the commonly used p-y method and it carries out the analysis using finite difference method. COM624P analyzes the laterally loaded single isolated pile for internal forces and for deflection line in pile.

We will use COM624P to get the value of performance function M_{Max} and Y_{Top} for the varying random design variables. The sample of the Input and Output file for

COM624P is shown in Appendix A and the results of the structural analysis of isolated single pile are shown in Appendix C to Appendix F.

5.6 Structural Analysis of Pile Group

The analysis of piles in group is similar to analyzing the single isolated pile. The only difference is that the p values in p-y curve for pile group are reduced by p-multiplier to account for reduced efficiencies caused by pile-soil-pile interaction. The p-multiplier concept was first developed by Brown et al. in 1988. After that many researchers did deep investigation into this approach through full-scale, centrifuge, and 1g model tests and in 2001, Mokwa & Duncan introduced an updated values of p-multiplier which is shown in Figure 5.4.

This study is conducted on the free head and fixed head long pile groups with center-to-center spacing of 3D, 4D, and 5D between piles. Here D indicates the diameter of pile.

Computer program **FB-MultiPier** (Florida Bridge Software Institute, 2000) version 4.0 is used to analyze pile group for maximum bending moment and pile head deflection. FB-MultiPier is developed by Florida Bridge Software Institute. It is more advanced than COM624P in respect of analyzing power and graphics. Unlike, the COM624P, it can analyze the pile group successfully and show the results in 3D-graphics. It can also be used for dynamic analysis. FB-MultiPier carries out the analysis using p-y curve and through FEM (Finite Element Method). In the modeling, all segment boundaries or nodes which fall below ground level receive a soil spring support. Properties of pile, lateral load on pile and the soil surrounding the pile are allocated and the pile contribution to the global stiffness matrix is formed. Two degrees of freedom per

node, rotation, and lateral deflection are considered; stiffness matrix formation follows the standard procedures for structural analysis. The Input and Output file for FB-MultiPier is shown in Appendix B and the results of the analysis of pile group are shown in Appendix G to Appendix L.

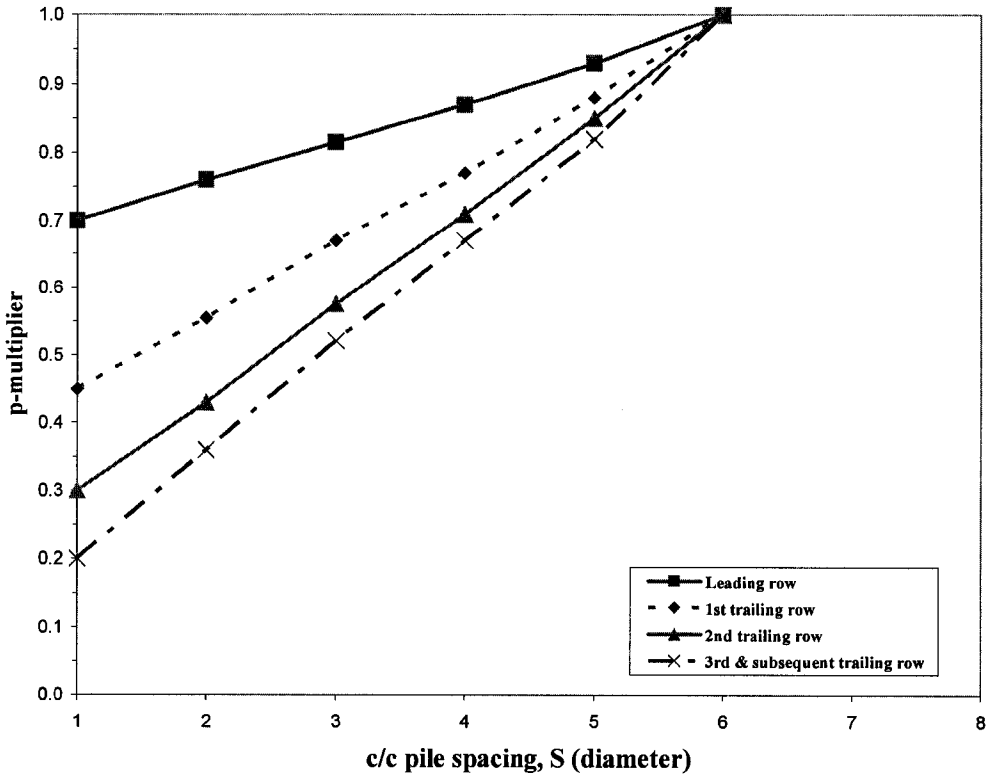


Fig. 5.4 Proposed p-multiplier design curves. (Mokwa & Dunkan, 2001)

5.7 Probabilistic Modeling of Laterally Loaded Pile and Pile Group

The main goal behind conducting this process is to find the COV, mean and standard deviation (Variance) of Y_{Top} and M_{Max}, which will be needed later in performing the reliability analysis.

Vector $\overline{X}$ of major random design variables for laterally loaded piles is given as:

$$\{X\}^T = \{B, EI, C, k, \varepsilon_{50}, \gamma'\} \quad \text{..... (5.23)}$$

Vector $\overline{f}(\overline{X})$ of function of random design variable for laterally loaded piles is defined as:

$$\{f(\overline{X})\}^T = \{Y_{Top}, M_{Max}\} \quad \text{..... (5.24)}$$

Random parameters $\overline{X}$ are characterized by their mean value $\overline{X}°$ and covariance matrix $[S_X]$.

Mean (Expected) values of random variables are specified as follows:

$$\{X°\}^T = \{B°, EI°, C°, k°, \varepsilon_{50}°, \gamma'^{0}\} \quad \text{..... (5.25)}$$

The covariance matrix $[S_X]$ for random variables contains random variables of vector $\overline{X}$ which are uncorrelated to each other. Thus,

$$[S_X] = \begin{bmatrix} Var(B) & 0 & 0 & 0 & 0 & 0 \\ 0 & Var(EI) & 0 & 0 & 0 & 0 \\ 0 & 0 & Var(C) & 0 & 0 & 0 \\ 0 & 0 & 0 & Var(k) & 0 & 0 \\ 0 & 0 & 0 & 0 & Var(\varepsilon_{50}) & 0 \\ 0 & 0 & 0 & 0 & 0 & Var(\gamma') \end{bmatrix} \quad \text{.. (5.26)}$$

Mean (Expected) value of vector of function of random variables $\overline{f°(X)}$ is given as:

$$\{f°(\overline{X})\}^T = \{Y_{Top}°, M_{Max}°\} \quad \text{..... (5.27)}$$

The covariance matrix of vector of function of random variables is specified in the following fashion:

Vectors of function are mutually independent.

$$\therefore [S_{f(\overline{X})}] = \begin{bmatrix} Var(Y_{Top}) & 0 \\ 0 & Var(M_{Max}) \end{bmatrix} \quad \text{..... (5.28)}$$

To carry out the probabilistic modeling it is very important to know the relationship between functions of random variables $\overline{f}(\overline{X})$ and random variables. The method of probabilistic modeling is different for linear (Section 4.1.4, Chapter 4) and non-linear (Section 4.1.5, Chapter 4) relationship. To find out the relationship, curves are drawn between functions and random variables. Sample curves are given in Fig. 5.5 and Fig. 5.6 which shows the relation between random variable C and the function of random variable Y_{Top} and M_{Max}.

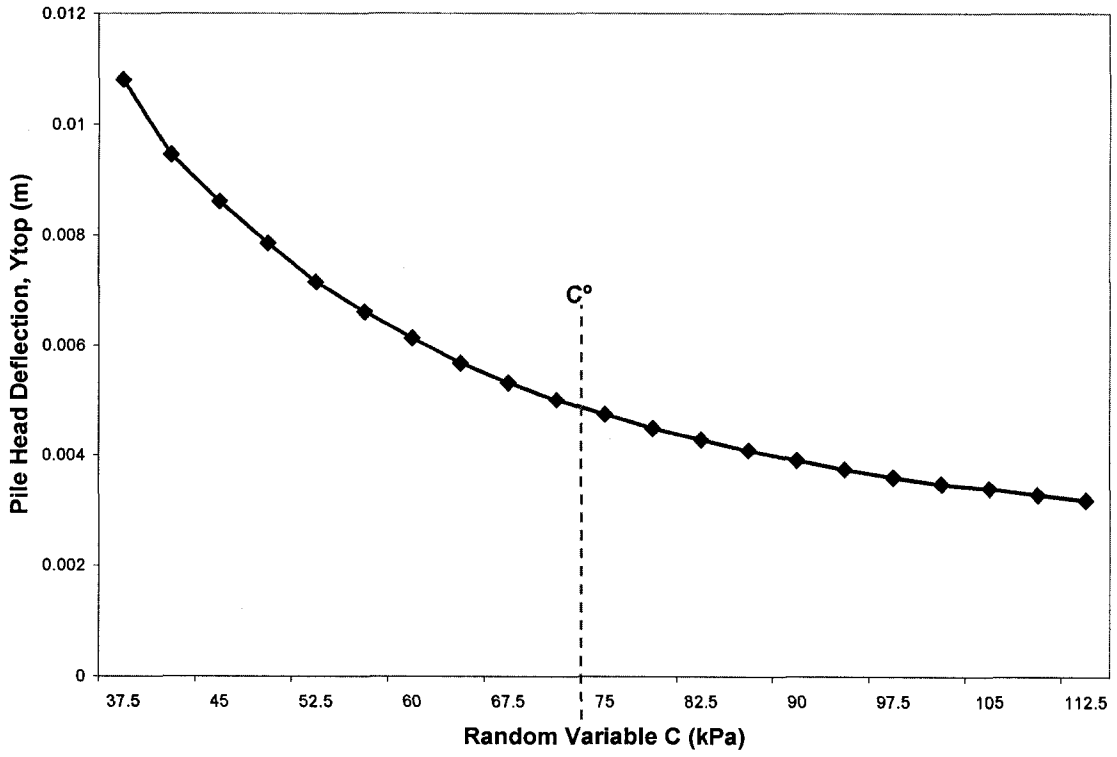


Fig. 5.5 Non-linear relationship between Y_{Top} and random variable C

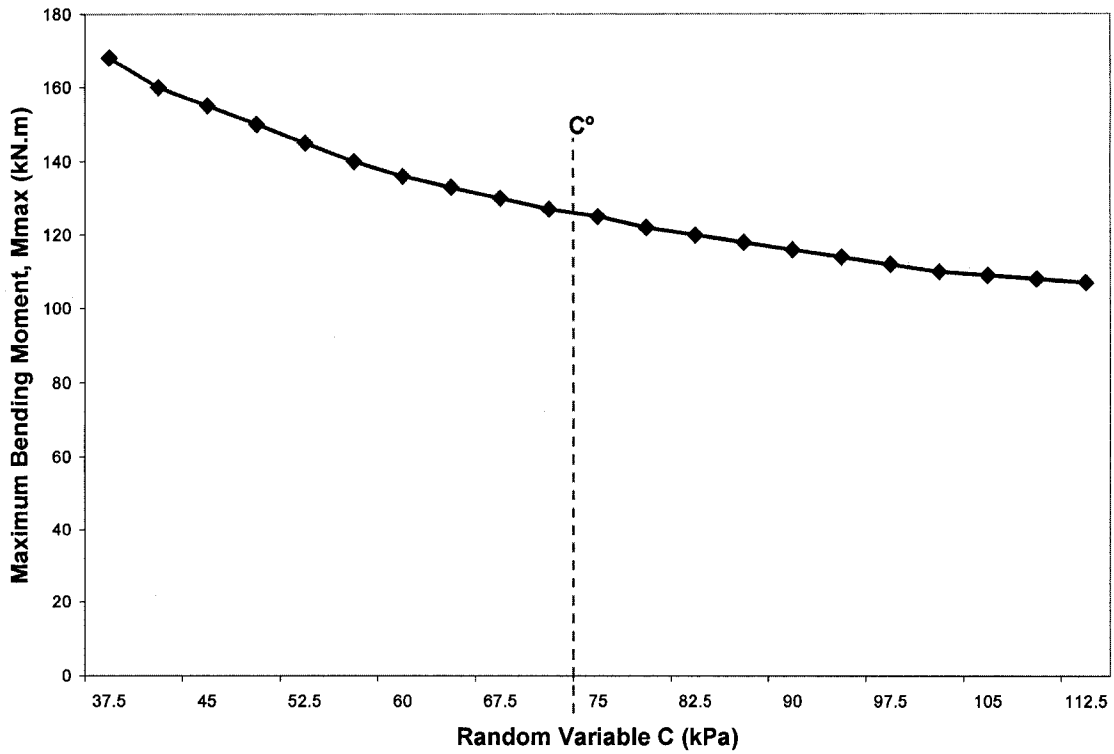


Fig. 5.6 Non-linear relationship between M_{Max} and random variable C

It is clearly visible in Fig. 5.5 and Fig. 5.6 that the relationship between functions and their variables in laterally loaded pile structure is non-linear. Therefore, using the formula given in Section 4.1.5, Chapter 4 (using Taylor series approximation), the variance matrices $Var(Y_{Top})$ and $Var(M_{Max})$ of functions of random variables can be given as:

$$[Var(Y_{Top})] = \left[\left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial B}\right)^2 \left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial EI}\right)^2 \left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial C}\right)^2 \left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial k}\right)^2 \left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial \varepsilon_{50}}\right)^2 \left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial \gamma'}\right)^2\right] \begin{bmatrix} Var(B) \\ Var(EI) \\ Var(C) \\ Var(k) \\ Var(\varepsilon_{50}) \\ Var(\gamma') \end{bmatrix} \cdots$$

..... (5.29)

For details refer Chapter 4.

and,

$$[Var(M_{Max})]=\begin{bmatrix}\left(\frac{\partial M_{Max}(\overline{X^{\circ}})}{\partial B}\right)^2 & \left(\frac{\partial M_{Max}(\overline{X^{\circ}})}{\partial EI}\right)^2 & \left(\frac{\partial M_{Max}(\overline{X^{\circ}})}{\partial C}\right)^2 & \left(\frac{\partial M_{Max}(\overline{X^{\circ}})}{\partial k}\right)^2 & \left(\frac{\partial M_{Max}(\overline{X^{\circ}})}{\partial \varepsilon_{50}}\right)^2 & \left(\frac{\partial M_{Max}(\overline{X^{\circ}})}{\partial \gamma'}\right)^2\end{bmatrix}\begin{bmatrix}Var(B)\\ Var(EI)\\ Var(C)\\ Var(k)\\ Var(\varepsilon_{50})\\ Var(\gamma')\end{bmatrix} \quad \text{..... (5.30)}$$

As the above equation is evaluated at the mean values of random variables, the elements of the sensitivity matrix can be determined as:

$$\left(\frac{\partial Y_{Top}(\overline{X^{\circ}})}{\partial B}\right)=\left(\frac{Y_{Top}^{Current}-Y_{Top}^{\circ}}{B^{Current}-B^{\circ}}\right) \quad \text{..... (5.31)}$$

Same way we can calculate value for other first-derivatives for Y_{Top} and M_{Max} connected to other random variables.

It is very beneficial to calculate coefficient of variation (COV) of functions from the variance and mean values of functions. These COV are useful to design engineers and researchers, in case of availability of insufficient data from soil exploration and laboratory tests. The COV of functions can be calculated as;

$$COV(Y_{Top})=\frac{\sigma_{Ytop}}{(Y_{Top})^{\circ}} \quad \text{..... (5.32)}$$

and for M_{Max},

$$COV(M_{Max})=\frac{\sigma_{MMax}}{(M_{Max})^{\circ}} \quad \text{..... (5.33)}$$

Sample calculation from the study

For a better understanding of the concept, one example from the study is shown here.

Free head single isolated short pile has a lateral load of 100 kN with the mean values of random design variables:

$B^o = 0.508$ m; $EI^o = 110x10^3$ kN.m^2 $C^o = 75$ kPa

$k^o = 136000$ kN/m^3 $\varepsilon_{50}{}^o = 0.007$ $\gamma'^o = 5.9$ kN/m^3

Using Program COM624P, we get

$$M_{Max}{}^\circ = 85.3kN \cdot m \quad \text{..... (5.34)}$$

To evaluate the Var(Y_{Top}) for the random variable C, keep the values all the other random variables at their mean.

$$Var(M_{Max})_C = \left(\frac{\partial M_{Max}(\overline{X})}{\partial C}\right)^2 \Big|_0 Var(C) \quad \text{..... (5.35)}$$

Suppose the design random variable C varied by 5% from its mean value on both side.

$$C^+ = 78.75kPa$$
$$C^- = 71.25kPa$$

and, Coefficient of Variation (COV) = 5%

also, we know that,

$$COV_C = \frac{\sigma_C}{C^\circ} \quad \text{..... (5.36)}$$

$$\Rightarrow \sigma_C = COV_C * C^\circ$$
$$\Rightarrow \sigma_C = 0.05 * 75$$

$$\therefore \sigma_C = 3.75kPa \quad \text{..... (5.37)}$$

Now,

$$Var(C) = (\sigma_C)^2 \quad \text{..... (5.38)}$$

$$\therefore Var(C) = 14.06(kPa)^2 \quad \text{..... (5.39)}$$

Using Program COM624P, we get,

$$M^{+}_{Max} = 83.9kN \cdot m \quad \text{..... (5.40)}$$

$$M^{-}_{Max} = 87kN \cdot m \quad \text{..... (5.41)}$$

Therefore,

$$Var(M_{Max})_{C\to 5\%} = \left(\frac{M^{+}_{Max} - M^{-}_{Max}}{C^{+} - C^{-}}\right)^2 * Var(C) \quad \text{..... (5.42)}$$

$$\Rightarrow Var(M_{Max})_{C\to 5\%} = \left(\frac{83.9 - 87}{78.75 - 71.25}\right)^2 * (14.06)$$

$$\therefore Var(M_{Max})_{C\to 5\%} = 2.4(kN.m)^2 \quad \text{..... (5.43)}$$

and,

$$COV(M_{Max})_{C\to 5\%} = \frac{\sigma_{MMax}}{M_{Max}^{\circ}} \quad \text{..... (5.44)}$$

$$\Rightarrow COV(M_{Max})_{C\to 5\%} = \frac{\sqrt{Var(M_{Max})_{5\%}}}{M_{Max}^{\circ}} \quad \text{..... (5.45)}$$

$$\therefore COV(M_{Max})_{C\to 5\%} = \frac{\sqrt{2.4}}{85.3} = 0.01817$$

$$Or, COV(M_{Max})_{C\to 5\%} = 1.817\% \quad \text{..... (5.46)}$$

Same way, we can go for 10%, 15%, and so on (refer the appendices). Also to see the effect of lateral load along with other random variables (connected to pile and surrounding soil) on performance of pile structure, lateral load with discrete variability is applied to the pile head. The graph between COV(C) and COV(M_{Max}) for lateral load of discrete variability is shown in Fig. 5.7. Above procedure should be carried out for the serviceability (Y_{Top}) too.

After the random variable C, the pile should be analyzed for other 5 random variables individually that is B, EI, k, ε_{50}, and γ'. To conduct a comprehensive study, laterally loaded pile is analyzed for different lengths of pile (short 3T, and long 10T), different boundary conditions (free head, and fixed head), and pile group with different center-to-center pile spacing (3D, 4D, and 5D). Probabilistic modeling of pile group is carried out the same way as single isolated pile, but with different M_{Max} value for each row i.e. Leading, 1st, and 2nd trailing row.

All the results of probabilistic modeling on single isolated pile and pile group are shown in Appendix C through Appendix L and the detailed discussion on the results of free head short and long pile, fixed head short and long pile, and free and fixed head pile groups is given in Chapter 6.

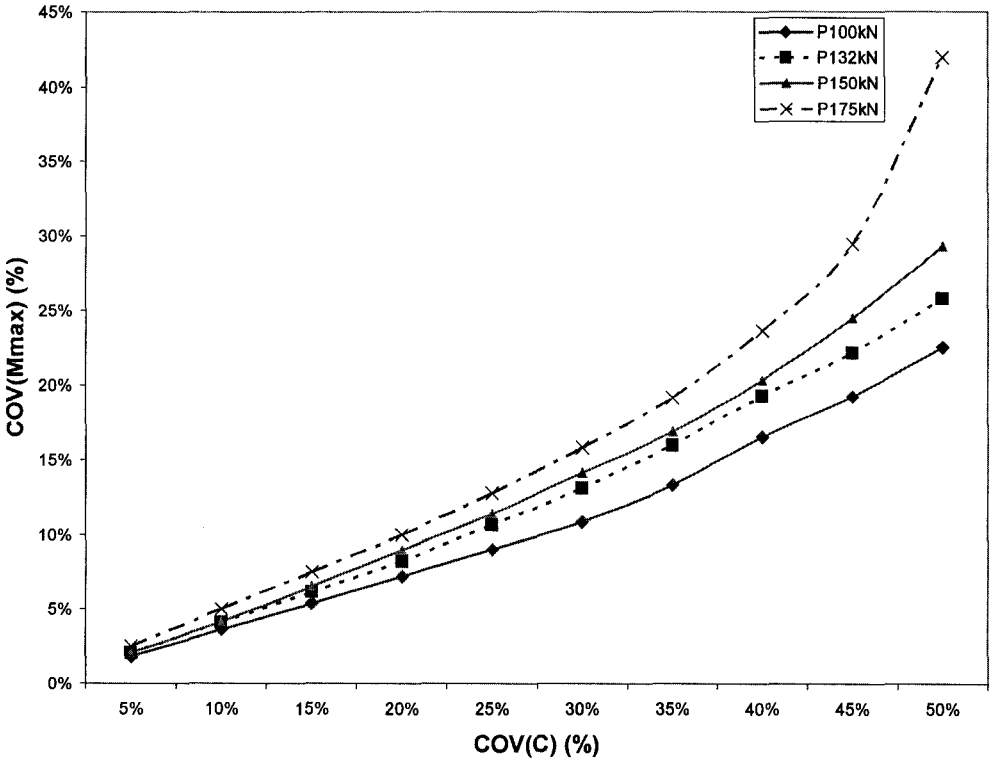


Fig. 5.7 Graph between COV(C) and COV(M_{Max}) for free head single isolated short pile.

5.8 Reliability analysis with First-Order Second-Moment Reliability Method (FOSM)

Reliability analysis requires the joint distribution of all design random variables and considerable mathematical and numerical processing of data. Other way is to go for Monte Carlo simulation to evaluate the performance function for assumed distributions of the design random variables. In reality, the available information or data is only sufficient to evaluate the mean and variance of the design random variables. Consequently, practical measures of reliability would have to be based on the FOSM.

The limit state function $\overline{g(f)}$ is given by:

$$\overline{g(f)} = \overline{f^{Resist}} - \overline{f^{Current}} \quad \text{..... (4.47)}$$

where,

$$\{g(f)\}^T = \{g(Y_{Top}), g(M_{Max})\} \quad \text{..... (4.48)}$$

$$\{f^{Resist}\}^T = \{Y_{Top}^{Resist}, M_{Max}^{Resist}\} \quad \text{..... (4.49)}$$

$$\{f^{Current}\}^T = \{Y_{Top}^{Current}, M_{Max}^{Current}\} \quad \text{..... (4.50)}$$

To calculate the reliability index connected to serviceability (β_{Ytop}) and strength (β_{Mmax}), we need mean and variance of limit state function $\overline{g(f)}$.

$$g^{\circ}(Y_{Top}) = (Y_{Top}^{Resist})^{\circ} - (Y_{Top}^{Current})^{\circ} \quad \text{..... (4.51)}$$

and,

$$g^{\circ}(M_{Max}) = (M_{Max}^{Resist})^{\circ} - (M_{Max}^{Current})^{\circ} \quad \text{..... (4.52)}$$

also,

$$Var(g(Y_{Top})) = Var(Y_{Top}^{Resist}) + Var(Y_{Top}^{Current}) \quad \text{..... (4.53)}$$

and,

$$Var(g(M_{Max})) = Var(M_{Max}^{Resist}) + Var(M_{Max}^{Current}) \quad \text{..... (4.54)}$$

Therefore reliability index connected to serviceability and ultimate strength is given by

$$\beta_{Ytop} = \left(\frac{\left(g(Y_{Top})\right)^{\circ}}{\sigma_{g(Ytop)}} \right) \quad \text{..... (4.55)}$$

or,

$$\beta_{Ytop} = \left(\frac{\left(Y_{Top}^{Resist}\right)^{\circ} - \left(Y_{Top}^{Current}\right)^{\circ}}{\sqrt{Var\left(Y_{Top}^{Resist}\right) + Var\left(Y_{Top}^{Current}\right)}} \right) \quad \text{..... (4.56)}$$

same way for β_{Mmax},

$$\beta_{M\max} = \left(\frac{\left(M_{Max}^{Resist}\right)^{\circ} - \left(M_{Max}^{Current}\right)^{\circ}}{\sqrt{Var\left(M_{Max}^{Resist}\right) + Var\left(M_{Max}^{Current}\right)}} \right) \quad \text{..... (4.57)}$$

Determination of $\overline{f^{Resist}}$:

The values of $\overline{f^{Current}}$ are obtained from structural analysis and probabilistic modeling of laterally loaded pile structure, but as $\overline{f^{Resist}}$ is independent of the pile-soil interaction i.e. not a function of design random variables, we have to assess its value from literature such as design codes and other literature.

We know that laterally loaded pile is analyzed as a beam-column and its resistance statistics is available in Table 5.2.

Table 5.2 Typical load and resistance statistics for structures

(Data from Ellingwood et al. 1982)

	COV (%)
Load*	
Dead	10
Live	25
Wind	37
Snow	26
Earthquake	138
Resistances	
Concrete	
Flexure beams	8 to 14
Short columns	12 to 16
Slender columns	12 to 17
Shear beams	17 to 21
Steel	
Tension members	11
Compact beams, uniform moment	13
Axially loaded columns	14
Beam-columns	15
Aluminum	
Tension members	8
Beams	8 to 13
Columns	8 to 14
Glue-laminated timber beams	18

*Fifty years maximum load effects.

As shown in Table 5.2, the COV for beam-column is 15%, but as the pile is a geotechnical structure and usually geotechnical variability is higher than structural variability (Refer: Evaluation of geotechnical property variability by K. K. Phoon &F. H. Kulhawy, 1999), the COV for resistance of steel pile $\left(\overline{f^{Resist}}\right)$ is taken as 20%.

Sample Calculation from the Study

Continuing with the same above example which we solved for $Var(M_{Max})_{5\%}$ and $COV(M_{Max})_{5\%}$ with varying random variable C and other variables are at their respective mean values.

we got,

$$M_{Max}^{Current\,\circ} = 85.3kNm \quad \text{..... (5.58)}$$

$$Var(M_{Max}^{Current})_{C\to 5\%} = 2.4(kNm)^2 \quad \text{..... (5.59)}$$

and, we know,

$$M_{Max}^{Resist\,\circ} = \text{Plastic Modulus of pile}$$

$$M_{Max}^{Resist\,\circ} = 894kN\cdot m \quad \text{..... (5.60)}$$

and,

$$COV\left(M_{Max}^{Resist}\right) = 20\% \quad \text{..... (5.61)}$$

therefore,

$$\Rightarrow \sigma_{M_{Max}^{Resist}} = COV\left(M_{Max}^{Resist}\right) * \left(M_{Max}^{Resist}\right) \quad \text{..... (5.62)}$$

$$\Rightarrow \sigma_{M_{Max}^{Resist}} = 0.2 * 894 = 178.8kNm \quad \text{..... (5.63)}$$

$$\therefore Var\left(M_{Max}^{Resist}\right) = \left(\sigma_{M_{Max}^{Resist}}\right)^2 = 31969.44(kNm)^2 \quad \text{..... (5.64)}$$

Now,

$$g^{\circ}(M_{Max}) = \left(M_{Max}^{Resist}\right)^{\circ} - \left(M_{Max}^{Current}\right)^{\circ} \quad \text{..... (5.65)}$$

$$\Rightarrow g^{\circ}(M_{Max}) = 894 - 85.3$$

$$\Rightarrow g^{\circ}(M_{Max}) = 808.7kNm \quad \text{..... (5.66)}$$

and,

$$Var(g(M_{Max}))_{C\to 5\%} = Var\left(M_{Max}^{Resist}\right) + Var\left(M_{Max}^{Current}\right)_{C\to 5\%} \quad \text{..... (5.67)}$$

$$\Rightarrow Var(g(M_{Max}))_{C\to 5\%} = 31969.44 + 2.4$$

$$\Rightarrow Var(g(M_{Max}))_{C\to 5\%} = 31971.84(kNm)^2 \quad \text{..... (5.68)}$$

therefore,

$$(\beta_{M\max})_{C\to 5\%} = \left(\frac{g^{\circ}(M_{Max})}{\sigma_{g(M\max)}}\right)_{5\%} \quad \text{..... (5.69)}$$

$$\Rightarrow (\beta_{M\max})_{C\to 5\%} = \left(\frac{808.7}{\sqrt{31971.84}}\right)$$

$$\therefore (\beta_{M\max})_{C\to 5\%} = 4.52 \quad \text{..... (5.70)}$$

As per the recommendations of Nordic Committee on Building Regulations (NKB) (Table 4.1, Chapter 4) for ultimate limit states, the minimum reliability index needed for safe structure is 3.7 for a 1 year reference period. In the above example, we got reliability index of 4.52. Therefore it shows that this structure is safe even if design random variable C (undrained shear strength) varies by $\pm 5\%$ from its mean or expected value.

We can carry out the same procedure for 10%, 15%, and so on and for other design random variables; also for reliability index connected to serviceability. The graph between COV(C) and reliability index (β) connected to M_{Max} is shown in Figure 5.8.

Like the probabilistic analysis, reliability analysis is comprehensively conducted for free and fixed head piles, short and long pile, single isolated pile and pile group. In addition to that, discrete variability of lateral load is also taken into consideration.

All the results of reliability analysis connected to serviceability and ultimate strength for free and fixed head single isolated long and short piles and pile groups are shown in Appendix C through Appendix L. The detailed discussion on the results of reliability analysis is given in Chapter 6.

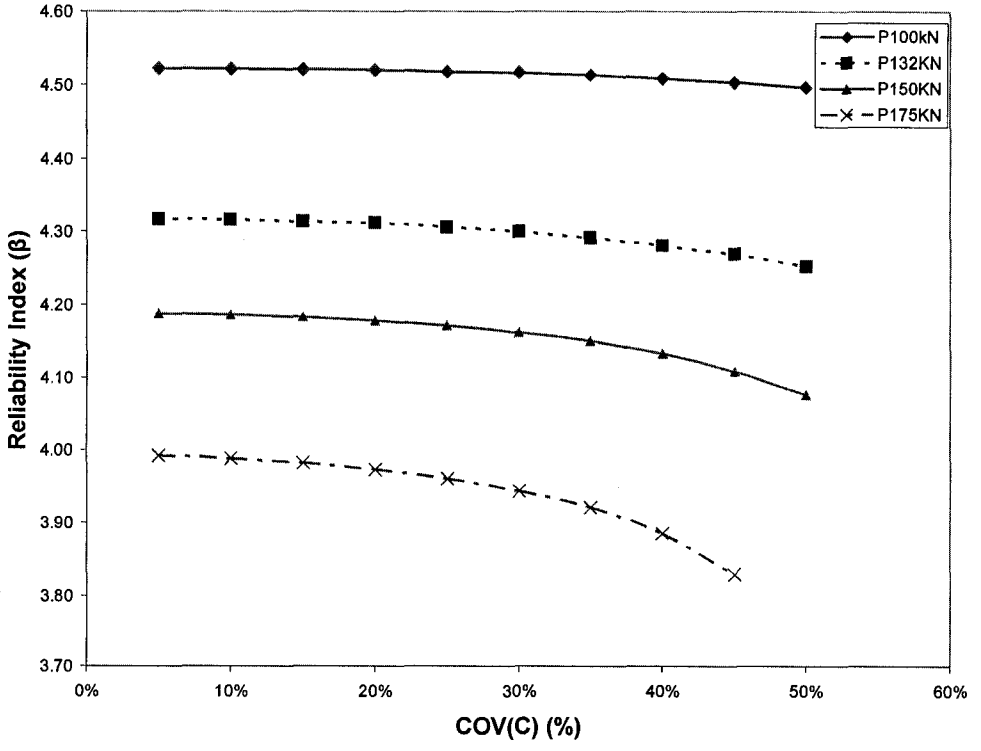


Fig. 5.8 Graph between COV(C) and Reliability Index (β) connected to M_{Max} for free head single isolated short pile with varying random variable 'C'.

5.9 Combined Load Analysis

The performance of pile structure for serviceability is also affected by uncertainties connected to applied lateral load (Section 3.6, Chapter 3), in addition to the uncertainties connected to pile material and soil profile. The parameters of applied lateral load include lateral load, P and moment M. Thus, to conduct probabilistic modeling and to carry out reliability analysis on pile structure, above parameters i.e. P and M need to be taken as random variables with their mean value and variance.

To observe the effect of uncertainties connected to applied lateral load on the performance of pile structure, combined load analysis is conducted. In combined load analysis four scenarios are considered. In first scenario, only lateral load, P is applied to pile head to get the pile head deflection. Based on the results, the curve is drawn between the lateral load P and pile head deflection Y_{Top}, to see the relationship between them. In the second scenario, only moment M is applied at pile head to observe the relationship between moment M and pile head deflection Y_{Top}. In the third scenario, the results of first and second scenario are superimposed to see the linear effect of combined load on serviceability of pile structure. In the fourth scenario, lateral load P and moment M are applied at the same time on pile head, to see the effect of combined load (linear and nonlinear) on the performance (serviceability) of the pile structure.

To carry out the combined load analysis, free head isolated single long (10T) pile is used. Lateral load, P and moment, M are taken as random variables with discrete variability. To observe the effect of random variables P and M on the pile structure, other random variables (B, EI, C, ε_{50}, k, γ') are kept at their mean value.

After getting the relation between P and Y_{Top}, and M and Y_{Top}, from scenario I and II (refer Chapter 6 for details), the mean value for P and M are selected in such a fashion that they both give the same deflection individually.

Scenario III: Linear effect of combined load on performance (serviceability) of pile structure

The mean value of P and M is varied at $\pm 5\%$ rate and applied separately to pile structure to get pile head deflection (Y_{Top}). Therefore, the pile head deflection (Y_{Top}) for linear system is given by,

$$Y_{Top}^{L} = Y_{Top}^{P} + Y_{Top}^{M}, where Y_{Top}^{P} = Y_{Top}^{M} \quad \text{..... (5.71)}$$

or,

$$Y_{Top}^{L} = 2\left(Y_{Top}^{P}\right) \quad \text{..... (5.72)}$$

The mean value of Y_{Top} for linear system is given by;

$$\left(Y_{Top}^{L}\right) = \left(Y_{Top}^{P}\right) + \left(Y_{Top}^{M}\right) = 2\left(Y_{Top}^{P}\right) \quad \text{..... (5.73)}$$

and the $Var\left(Y_{Top}^{L}\right)$ can be written as,

$$Var\left(Y_{Top}^{L}\right) = \left(\frac{\partial Y_{Top}^{L}}{\partial P}\right)(VarP) + \left(\frac{\partial Y_{Top}^{L}}{\partial M}\right)(VarM) \quad \text{..... (5.74)}$$

From the above equations, we can find out the value for $COV(Y_{Top}^{L})$,

$$COV(Y_{Top}^{L}) = \frac{\sqrt{Var\left(Y_{Top}^{L}\right)}}{\left(Y_{Top}^{L}\right)} \quad \text{..... (5.76)}$$

Reliability analysis connected to serviceability for scenario III

The limit state function for linear system $g\left(Y_{Top}^{L}\right)$ is given by,

$$g\left(Y_{Top}^{L}\right)=\left(Y_{Top}\right)^{Resist}-\left(Y_{Top}^{L}\right)^{Current} \quad \text{..... (5.77)}$$

Also mean value of limit state function $g\left(Y_{Top}^{L}\right)$ can be written as,

$$g\left(Y_{Top}^{L}\right)=\left\{\left(Y_{Top}\right)^{Resist}\right\}-\left\{\left(Y_{Top}^{L}\right)^{Current}\right\} \quad \text{..... (5.78)}$$

and, the variance of limit state function $Var\left\{g\left(Y_{Top}^{L}\right)\right\}$,

$$Var\left\{g\left(Y_{Top}^{L}\right)\right\}=Var\left\{\left(Y_{Top}\right)^{Resist}\right\}+Var\left\{\left(Y_{Top}^{L}\right)^{Current}\right\} \quad \text{..... (5.79)}$$

Therefore, reliability index $\left(\beta_{Ytop}^{L}\right)$ connected to serviceability is given in following equation,

$$\beta_{Ytop}^{L}=\left(\frac{\left(g(Y_{Ytop}^{L})\right)}{\sqrt{Var\left\{g(Y_{Ytop}^{L})\right\}}}\right) \quad \text{..... (5.80)}$$

Scenario IV: Non-linear effect of combined load on performance (serviceability) of pile structure

In this scenario, lateral load, P and moment, M are applied together to the pile head of free head long pile. Alike the scenario III, P and M are varied by 5% rate and other random variables are kept at their mean value to get pile head deflection, Y_{Top}.

The pile head deflection for non-linear system Y_{Top}^{NL} can be written as,

$$Y_{Top}^{NL}=Y_{Top}^{P+M} \quad \text{..... (5.81)}$$

and, the mean and variance for Y_{Top} for non-linear system can be given as,

$$\left(Y_{Top}^{NL}\right)=\left(Y_{Top}^{P+M}\right) \quad \text{..... (5.82)}$$

$$Var\left(Y_{Top}^{NL}\right)=\left(\frac{\partial Y_{Top}^{NL}}{\partial P}\right)(VarP)+\left(\frac{\partial Y_{Top}^{NL}}{\partial M}\right)(VarM) \quad \text{..... (5.83)}$$

Therefore, COV for Y_{Top} for non-linear system can be given by,

$$COV(Y_{Top}^{NL})=\frac{\sqrt{Var\left(Y_{Top}^{NL}\right)}}{\left(Y_{Top}^{NL}\right)^{\circ}} \quad \text{..... (5.84)}$$

Reliability analysis connected to serviceability for scenario IV

The limit state function for non-linear system $g\left(Y_{Top}^{NL}\right)$ is given by,

$$g\left(Y_{Top}^{NL}\right)=\left(Y_{Top}\right)^{Resist}-\left(Y_{Top}^{NL}\right)^{Current} \quad \text{..... (5.85)}$$

Also mean value of limit state function $g\left(Y_{Top}^{NL}\right)^{\circ}$ can be written as,

$$g\left(Y_{Top}^{NL}\right)^{\circ}=\left\{\left(Y_{Top}\right)^{Resist}\right\}^{\circ}-\left\{\left(Y_{Top}^{NL}\right)^{Current}\right\}^{\circ} \quad \text{..... (5.86)}$$

and, the variance of limit state function $Var\left\{g\left(Y_{Top}^{NL}\right)\right\}$,

$$Var\left\{g\left(Y_{Top}^{NL}\right)\right\}=Var\left\{\left(Y_{Top}\right)^{Resist}\right\}+Var\left\{\left(Y_{Top}^{NL}\right)^{Current}\right\} \quad \text{..... (5.87)}$$

Therefore, reliability index $\left(\beta_{Ytop}^{NL}\right)$ connected to serviceability for non-linear system is given in following equation,

$$\beta_{Ytop}^{NL}=\left(\frac{\left(g(Y_{Ytop}^{NL})\right)^{\circ}}{\sqrt{Var\left\{g(Y_{Ytop}^{NL})\right\}}}\right) \quad \text{..... (5.88)}$$

Results of the combined load analysis on free head single long (10T) are shown comprehensively in Appendix M and the detailed discussion on the results is given in Chapter 6.

CHAPTER 6

DISCUSSION ON RESULTS

Probabilistic modeling and reliability analysis is conducted on laterally loaded single pile and pile group to get coefficient of variation (COV) and reliability index (β) for ultimate limit state (M_{Max}) and serviceability limit state (Y_{Top}).

When the data obtained from site exploration and laboratory testing is not sufficient to carry out a design of laterally loaded structure or to conduct safety checks i.e. ultimate and serviceability limit state, practicing engineers can use these COV obtained from this study to guess at the unavailable data.

The reliability index obtained from reliability analysis is helpful in checking the structure for limit states. In 1978, Nordic Committee on Building Regulation has suggested some values of reliability index for serviceability and ultimate limit states. The reliability index (β) for pile head deflection (Y_{Top}) should be greater than or equal to 2 and the reliability index for maximum bending moment (M_{Max}) in the pile or the leading row pile in the pile group should be greater than or equal to 3.7 (Refer Table 4.1).

6.1 Discussion on the results of laterally loaded free head single short (3T) pile

As the study undertaken on laterally loaded pile is very comprehensive, the discussion on the results of each kind of pile is divided into three parts i.e. discussion

connected to the relation between lateral load and p-y curve, the probabilistic modeling, and the reliability analysis.

6.1.1 Relationship between p-y curve and lateral load at pile head

We discussed in Chapter 3 that p-y curve for stiff clay below water table is divided into five phases - initial linear, first parabolic, second parabolic, second straight, and the plastic stage portion.

For the first case i.e. laterally loaded single short (3T) pile (Appendix C), four discrete lateral loads are selected to carry out the probabilistic modeling and to conduct reliability analysis. Each lateral load used for analysis represents one out of five phases of p-y curve. As shown in Fig. 6.1, the first lateral load 100 kN gives the pile head deflection of 0.00291 m and hence it represents the first linear phase in p-y curve for stiff clay below water table. The second lateral load 132 kN causes the pile head deflection of 0.00456 m and represents the first parabolic phase of p-y curve. This 132 kN also gives the maximum soil reaction at the pile head and therefore we called it optimum load. The third lateral load 150 kN gives pile head deflection of 0.00561 m and corresponds to the second parabolic phase. The fourth one, 175 kN, with 0.0077 m pile head deflection represents the second straight portion. Further increase in lateral load causes rapid increase in pile head deflection as the soil is going towards plastic stage and the results are not suitable to conduct reliability analysis. Therefore, lateral load representing the plastic stage is not considered in the analysis.

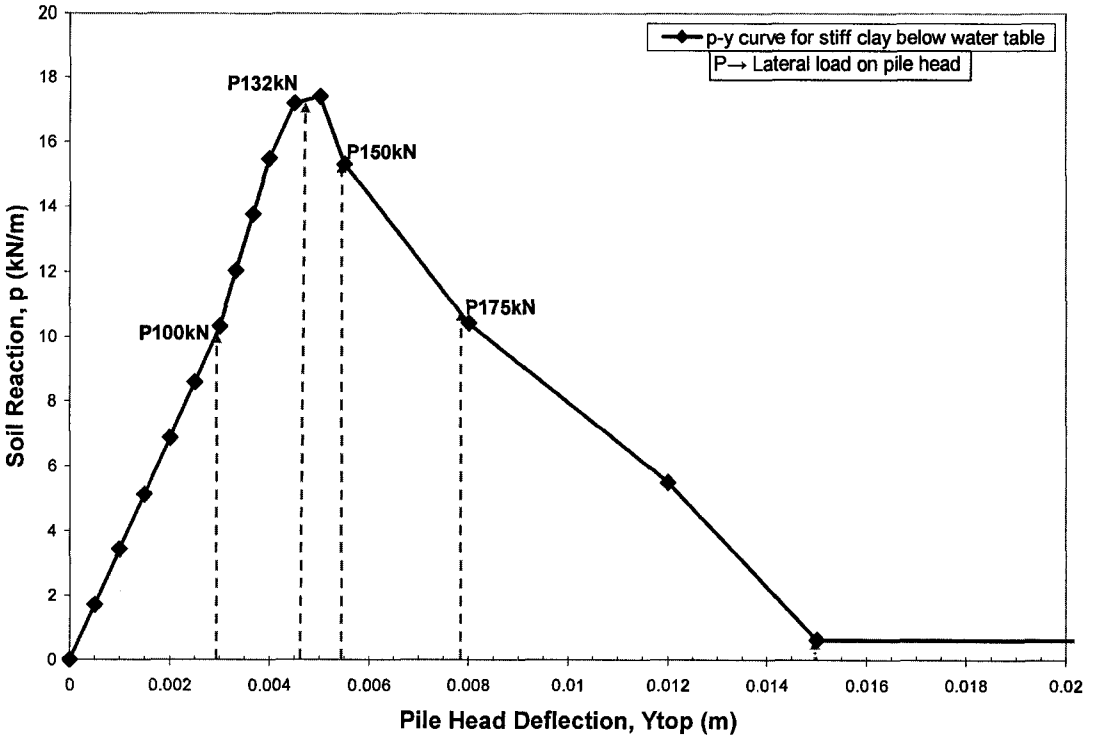


Fig. 6.1 Lateral loads representing the phases of p-y curve for stiff clay below water table in case of laterally loaded free head short (3T) pile.

6.1.2 Discussion on the probabilistic modeling of free head single short (3T) pile

Probabilistic modeling is divided into two parts. One is connected with the pile head deflection (Y_{Top}) and another one with the maximum bending moment in pile (M_{Max}).

The pinnacle intention in carrying out probabilistic modeling is to get the values of $Var(Y_{Top})$ and $Var(M_{Max})$, which will be further needed in performing the reliability analysis. The second reason is to get values of $COV(Y_{Top})$ and $COV(M_{Max})$, which will be useful to practicing engineers and researchers in assuming the unavailable data from site exploration and laboratory tests.

In probabilistic modeling, each random design variables is varied individually at some constant rate by keeping other variables at their mean value. When the first random design variable, B (Diameter of pile where soil reaction is acting), is varied at the rate of 5% from its mean value, the $COV(Y_{Top})$ has changed in some specific pattern (Fig. C.1, Appendix C). As we go away from the mean value of variable 'B', the $COV(Y_{Top})$ is increasing uniformly, but, when COV(B) crosses 40%, $COV(Y_{Top})$ starts rising rapidly. The applied lateral load at pile head also exhibits some effect on the $COV(Y_{Top})$. For the same value of COV(B), $COV(Y_{Top})$ is higher for higher lateral load. Above points are true for rest of the random design variables (C, EI, k, γ') too. The only exception is the variable ε_{50} (Fig. C.5, Appendix C). The $COV(Y_{Top})$ is decreasing as lateral load increases at some specific value of $COV(\varepsilon_{50})$. Unlike with the variable 'B', $COV(Y_{Top})$ does not rise very rapidly, as the COV(C, EI, ε_{50}, k, γ') crosses 40%. The affect of variability of these variables is different on Y_{Top}. Variable 'C' affects most with highest $COV(Y_{Top})$, then comes variable 'EI', after that variable 'B', then variable 'ε_{50}', then variable 'k', and at the end variable 'γ''. For COV(γ') equal to 50%, $COV(Y_{Top})$ is around 0.45% (refer Fig. 6.2). Same observation about γ' is also mentioned by K. K. Phoon and F. H. Kulhawy in their paper "Characterization of geotechnical variability".

Contrary to the case of $COV(Y_{Top})$, with $COV(M_{Max})$, only random design variable 'C' is showing considerable influence (Fig. C.4, Appendix C). All the other variables B, EI, ε_{50}, k, γ' cause comparatively small change. When the COV(B, EI, ε_{50}, k, γ') equal to 50%, the $COV(M_{Max})$ is less then 10%. Specially for random variables k and γ', the value for $COV(M_{Max})$ is lower than 1% (refer Fig. 6.3). It means maximum bending moment of laterally loaded pile is not affected by variables k and γ'. Similar to the case of $COV(Y_{Top})$, $COV(M_{Max})$ is also growing as the lateral load goes higher. Only

exception is the variable ε_{50} and EI (Fig. C.6, and Fig. C.8, Appendix C). Following is the variation of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of random variable:

Table 6.1 Values of $COV(Y_{Top})$ and $COV(M_{Max})$ for different random variable in free head single short (3T) pile.

Random Variable	COV(Variable) (%)	Max. $COV(Y_{Top})$ (%)	Max. $COV(M_{Max})$ (%)
C	0-50%	0 - 101.34%	0 - 42%
EI	0-50%	0 - 39.11%	0 - 5.33%
ε50	0-50%	0 - 19.25%	0 - 5.8%
B	0-50%	0 - 48.04%	0 - 8.33%
k	0-50%	0 - 4.3%	0 - 0.7%
γ'	0-50%	0 - 0.46%	0 - 0.2%

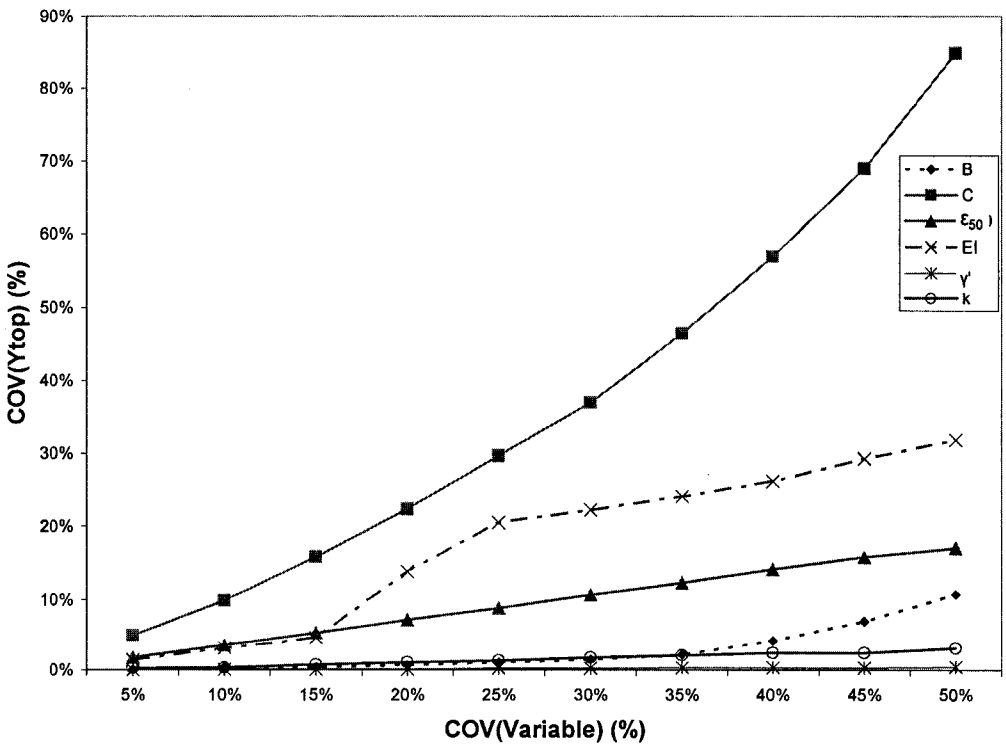


Fig. 6.2 Effect of different variables on $COV(Y_{Top})$ in free head single short (3T) pile at the optimum lateral load of 132 kN.

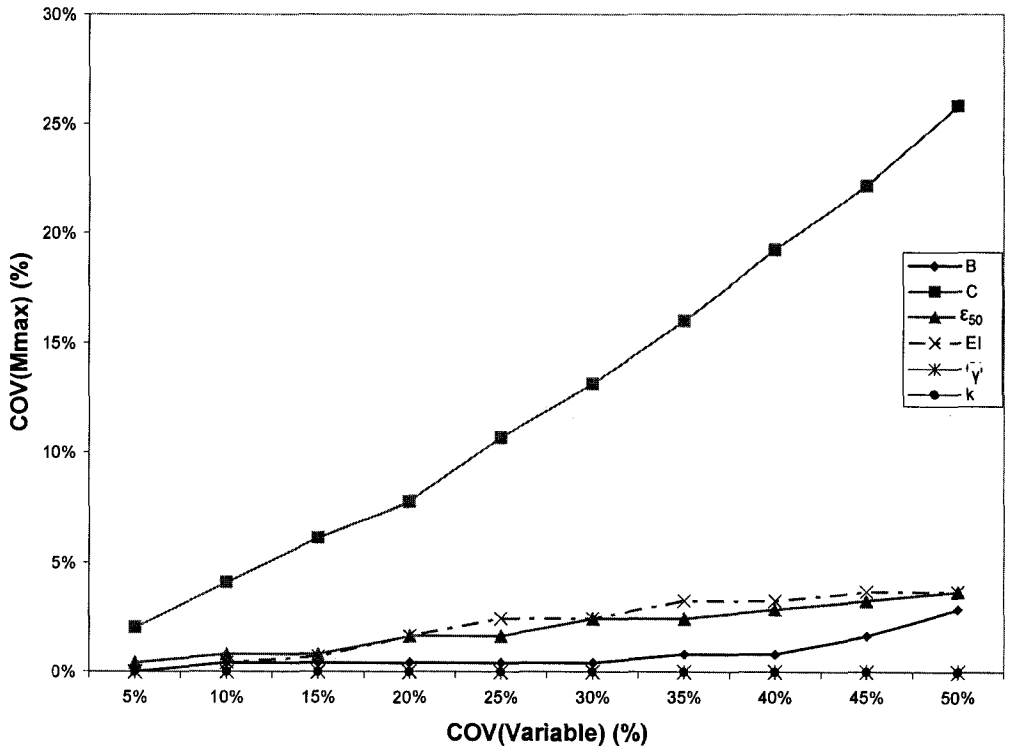


Fig. 6.3 Effect of variables on COV(M_{Max}) in free head single short (3T) pile at the optimum lateral load of 132 kN.

6.1.3 Discussion on the reliability analysis of free head single short (3T) pile

The key objective for conducting reliability analysis is to check the safety of the structure (here laterally loaded piles) through reliability index (β). Safety is connected with two parameters. First is ultimate limit state (maximum bending moment in pile, M_{Max}) and the second one, serviceability limit state (pile head deflection, Y_{Top}). For M_{Max}, reliability index (β) should be greater than or equal to 3.7 and for Y_{Top}, β should be greater than or equal to 2 (refer Table 4.1).

Reliability index is the inverse of COV. We have seen in the last section that when COV(variable) increases COV(Y_{Top}) and COV(M_{Max}) rises too. Therefore as per the definition of reliability index, it should go down with the increase in COV(variable). The results obtained from the reliability analysis proves the above point (refer Appendices).

The results show that the reliability index connected to Y_{Top} is very much dependent on the applied lateral load. As the load increases the reliability index is going down. Refer figure from C.17 to C.22 (Appendix C), it shows that for lateral load 100 kN (which represents first linear phase in p-y curve) reliability index is around 4.0 for all the variables, but when lateral load reaches 175 kN (which represents second straight portion in p-y curve) reliability index reduces to 2.0, which is very close to the failure. Results also indicate that the reliability index is very sensitive to the random variable 'C' (refer Fig. C13-C16, Appendix C). The top point of free head short piles fail at 40% of COV(C) for load 132 kN, at 30% of COV(C) for load 150 kN, and at 5% of COV(C) for load 175 kN. In descending order, the variables affecting reliability index connected to Y_{Top} are, C, EI, B, ε_{50}, k, and at the end γ'. In fact, variables k and γ' have very negligible effect on reliability index connected to Y_{Top}.

In case of reliability index connected to M_{Max}, the free head short (3T) pile structure is safe for all four loads i.e. 100 kN, 132 kN, 150 kN, and 175 kN. Results also indicate that only variable C is showing noticeable effect on reliability index connected to M_{Max}. The influence of other variables is negligible.

6.2 Discussion on the results of laterally loaded free head single long (10T) pile

6.2.1 Relationship between p-y curve and lateral load at pile head

Relationship between lateral load and p-y curve for stiff clay below water in free head single long (10T) pile is the same as the first case (free head short pile). Lateral load 100 kN represents first linear portion. Lateral load 132 kN corresponds to the first parabolic portion. Lateral load 150 kN corresponds to the second parabolic portion and the load 175 kN stands for the second straight portion. (Fig. 6.4)

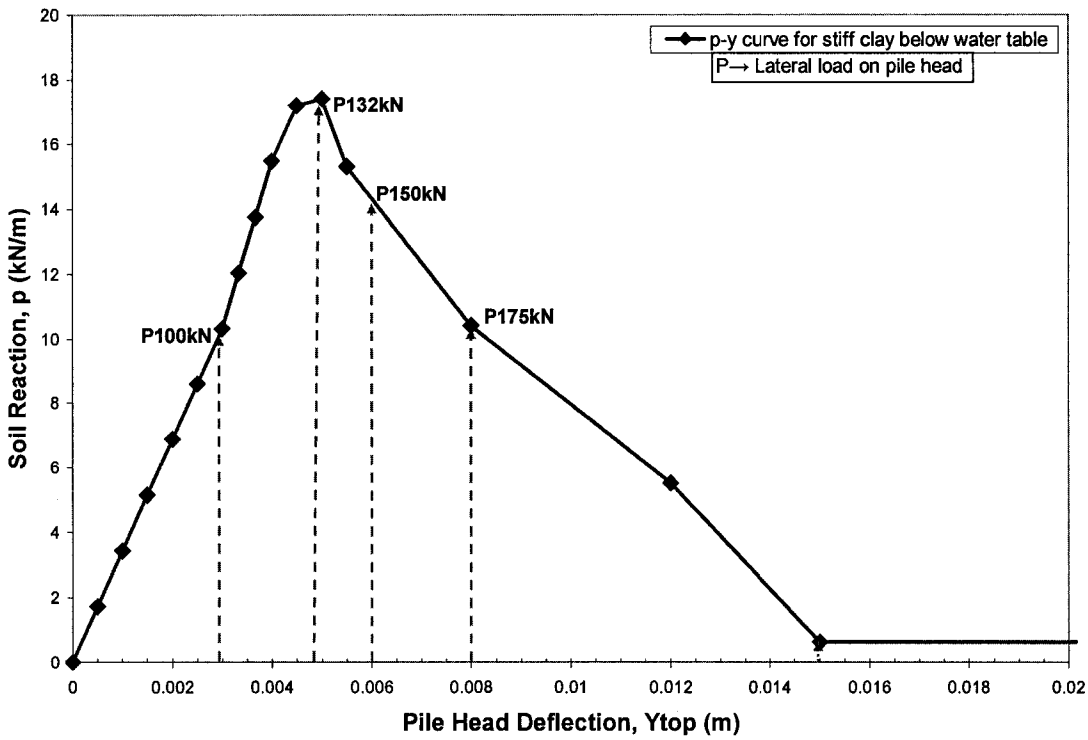


Fig. 6.4 Lateral loads representing the phases of p-y curve for stiff clay below water table in case of laterally loaded free head long (10T) pile.

6.2.2 Discussion on the probabilistic modeling of free head long (10T) piles

Difference between the first case and free head long (10T) pile, is the length of pile. In free head short pile, the length is 3T i.e. 6.15 m while the length of free head long pile is 10T i.e. 20.5 m. Instead of the vast difference in the length of two cases, results of probabilistic modeling indicate that the pattern and values are almost similar in both cases for all the variables (Fig. D.1-D.12, Appendix D). Means the pattern as well as the extent of variation of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of COV(variable) is almost similar in both cases. It implies that concerning the lateral load at pile head, there is no need of longer length. Even pile of shorter length can fulfill the same function. Table 6.2 shows the variability of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of random variable.

Table 6.2 Values of $COV(Y_{Top})$ and $COV(M_{Max})$ for different random variable in free head single long (10T) pile.

Random Variable	COV(Variable) (%)	Max. $COV(Y_{Top})$ (%)	Max. $COV(M_{Max})$ (%)
C	0-50%	0 - 124.3%	0 - 35.5%
EI	0-50%	0 - 43.3%	0 - 6.1%
ε50	0-50%	0 - 19.7%	0 - 6%
B	0-50%	0 - 48.04%	0 - 8.33%
k	0-50%	0 - 2.5%	0 - 1.4%
γ'	0-50%	0 - 0.5%	0 - 0.17%

6.2.3 Discussion on the reliability analysis of free head single long (10T) pile

Results for reliability index connected to Y_{Top} for free head long pile are almost similar to free head short pile; only difference is that the free head long (10T) pile is

failing at top under lateral load 175 kN with reliability index less than 2 (Fig. D.17-D.22, Appendix D). In descending order, the variables affecting reliability index connected to Y_{Top} are C→ EI→ ε_{50}→ B→ k→ γ' (Fig D.13-D.16, Appendix D). For the lateral load 132 kN and 150 kN, reliability index connected to Y_{Top} is less than 2 when COV(C) goes beyond 30%.

Results of reliability index connected to M_{Max} for free head long (10T) pile is almost similar to those for free head short (3T) pile (Fig. D.27-D.32, Appendix D). Variable C is the only variable noticeably affecting the reliability index connected to M_{Max} (Fig. D.23-D.26, Appendix D).

6.3 Discussion on the results of laterally loaded fixed head single short (3T) pile

Difference between the free head single short pile and fixed single short pile is the boundary condition. Fixed head short pile is embedded in the pile cap, which is assumed to be stiff enough to prevent rotation of pile head.

6.3.1 Relationship between p-y curve and lateral load at pile head

It is found out that to get the same deflection as of free head short pile, fixed head short pile must be loaded laterally with more than 2 times the load (Fig. 6.5). For example, to get pile head deflection of 0.008 m, we have to apply 175 kN (Fig. 6.1)to free head short pile while fixed head short pile needs 375 kN of lateral load.

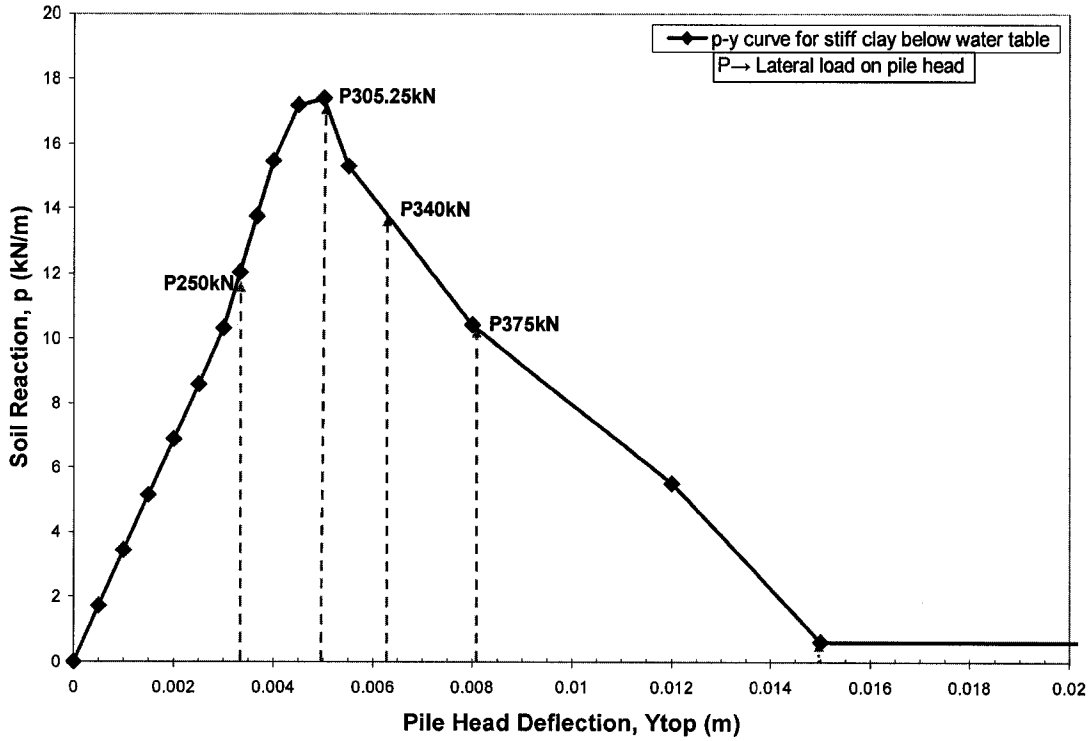


Fig. 6.5 Lateral loads representing the phases of p-y curve for stiff clay below water table in case of laterally loaded fixed head short (3T) pile.

6.3.2 Discussion on the probabilistic modeling of fixed head single short (3T) pile

Compared to free head short pile, fixed head short (3T) pile COV(Y_{Top}) is rising very rapidly as COV(B) and COV(C) increases at the rate of 5% (Refer Fig. E.1, appendix E). The top of fixed head pile fails at 20% of COV(B) and COV(C) for lateral load 375 kN, at 30% of COV(B) and COV(C) for lateral load 340 kN, and at 40% COV(B) and COV(C) for lateral load 305.25 kN. All other random variables are behaving in almost the same manner (just with little higher value of COV(Y_{Top})) as in free head short pile. In descending order the variables affecting COV(Y_{Top}) (Fig. 6.6): C→ EI→ B→ ε_{50}→ k→ γ'.

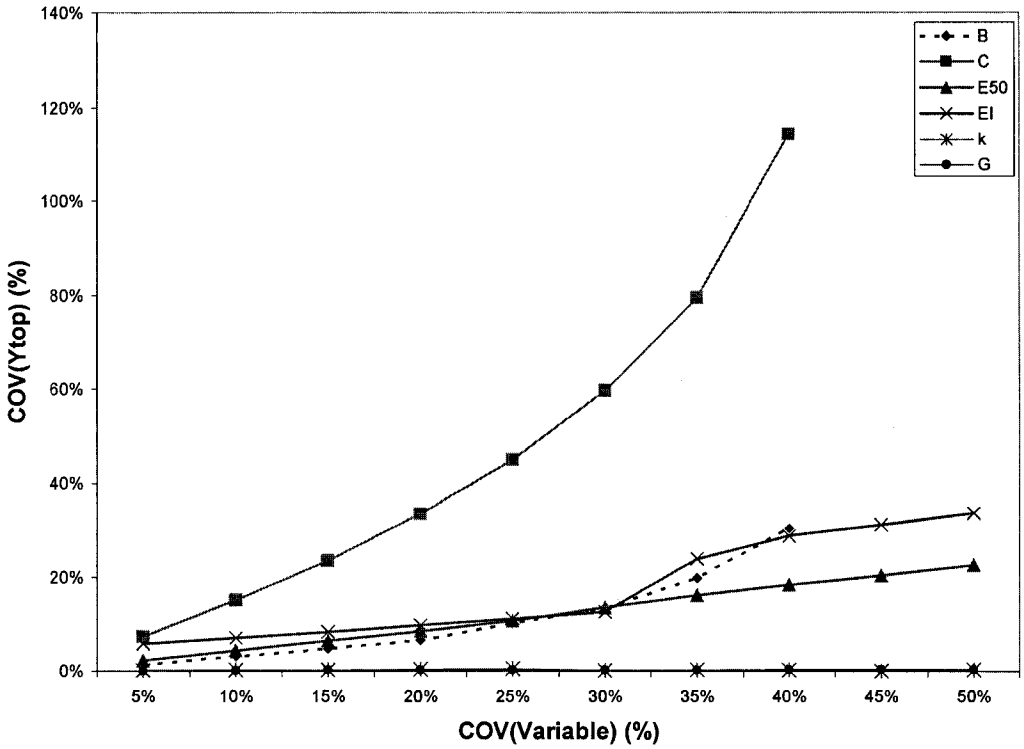


Fig. 6.6 Effect of different variables on COV(Y_{Top}) in fixed head single short (3T) pile at the optimum lateral load of 305.25 kN.

In fixed head short pile COV(M_{Max}) is showing the same pattern with COV(B) and COV(C) as COV(Y_{Top}) but with 1/3 values (Fig. E.2, and Fig. E.4, Appendix E). Also COV(M_{Max}) connected with other variables (EI, ε_{50}, k, γ') in fixed head short pile is higher than free head short pile but showing the same pattern. Table 6.3 shows the variability of COV(Y_{Top}) and COV(M_{Max}) with the variation of random variable.

Table 6.3 Values of COV(Y_{Top}) and COV(M_{Max}) for different random variable in fixed head single short (3T) pile.

Random Variable	COV(Variable) (%)	Max. COV(Y_{Top}) (%)	Max. COV(M_{Max}) (%)
C	0-50%	0 - 132.11%	0 - 33.5%
EI	0-50%	0 - 39.7%	0 - 7%
ε50	0-50%	0 - 23.6%	0 - 6.4%
B	0-25%	0 - 30.2%	0 - 9.4%
k	0-50%	0 - 1.5%	0 - 0.6%
γ'	0-50%	0 - 0.5%	0 - 0.25%

6.3.3 Discussion on the reliability analysis of fixed head single short (3T) pile

Overall the reliability index connected to Y_{Top} (β_{Ytop}) for fixed head short pile is slightly lower than for free head short pile. Same as the free head long (10T) pile, fixed head short (3T) pile has reliability index connected to Y_{Top} lower than 2 (indicate failure) for all the 6 random variables at load 375 kN (represents the second straight portion in p-y curve) (Fig. E.16, Appendix E). Fixed head short pile fails ($\beta_{Ytop}<2$) at top when COV(C) exceeds 45% for lateral load 250 kN, or 30% for lateral load 305.25 kN, or 20% for lateral load 340 kN. Also it fails when COV(B) surpass 40% for lateral load 305.25 kN and/or 30% for lateral load 340 kN. In descending order, random variable affecting β_{Ytop}: C→ B→ EI→ ε_{50}→ k→ γ' (Fig. E.13 – E.16, Appendix E).

Reliability index connected to M_{Max} (β_{Mmax}) for fixed head short pile is lower than the free head short pile for all 6 random variable (Fig. E.27-E.32, Appendix E). This indicates that boundary condition has very profound influence on β_{Mmax}. Results also show that β_{Mmax} is lower than 3.7 for all six variable at all four loads (Fig. E.27-E.32,

Appendix E). It mean that the fixed head short pile fails due to maximum bending moment (ultimate limit state). In descending order, random variables affecting β_{Mmax} : C→ B→ EI→ ε_{50}→ k→ γ' (Fig. E.23 – E.26, Appendix E).

6.4 Discussion on the results of laterally loaded fixed head single long (10T) pile

Fixed head single long (10T) pile is different from previous cases in two ways: pile length and boundary condition.

6.4.1 Relationship between p-y curve and lateral load at pile head

Figure 6.5 and 6.7 confirm that the increase in length from 3T (4.71 m) to 10T (15.7 m) do not markedly increase the deflection of pile head at some given lateral load. On contrary, boundary condition makes a large difference in deflection at pile head. For example, to get the pile head deflection of 0.005 m, 132 kN of lateral load is to be applied to free head long pile, whereas 305.25 kN (>2 times) of lateral load is needed in fixed head long pile to get same pile head deflection.

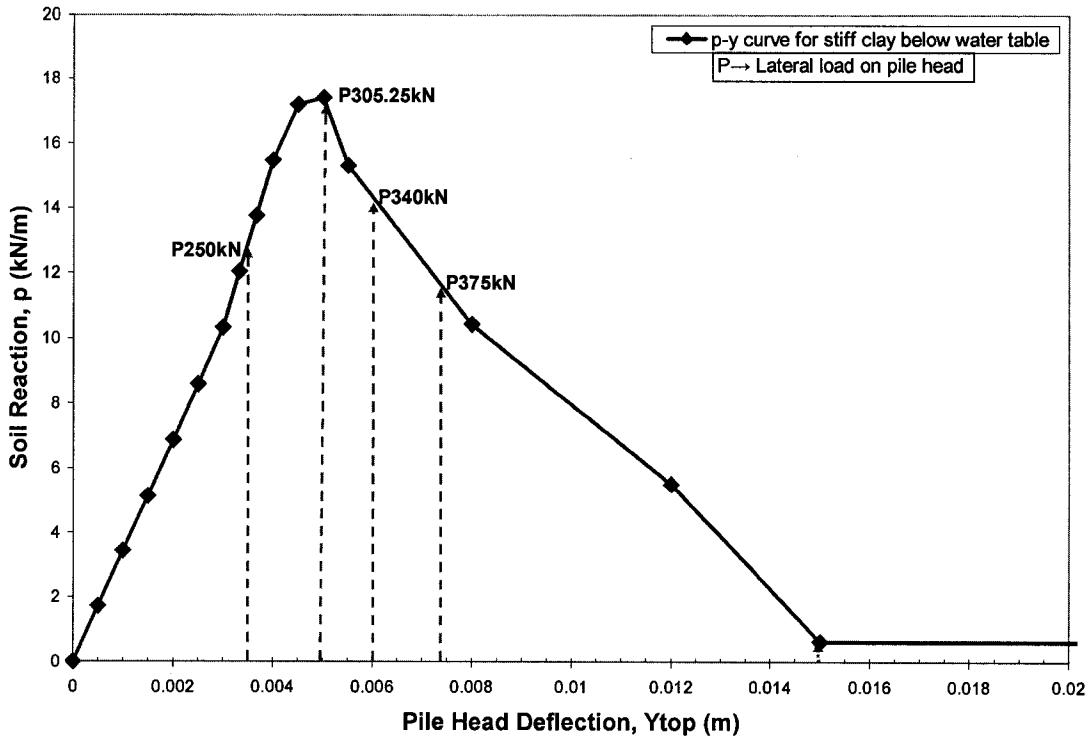


Fig. 6.7 Lateral loads representing the phases of p-y curve for stiff clay below water table in case of laterally loaded fixed head long (10T) pile.

6.4.2 Discussion on the probabilistic modeling of fixed head single long (10T) pile

When the length is increased from 3T to 10T, the curve between COV(B) or COV(C) and COV(Y_{Top}) gets less steep (Fig. F.1 and F.3, Appendix F). Means the structure is comparatively less vulnerable to failure. Same is with the variable ε_{50}. The COV(Y_{Top}) for fixed head long pile is little lower for fixed head short pile, but the pattern remains the same (Fig. F.5, Appendix F). For variables EI and γ', the values and pattern are almost similar for both cases i.e. fixed head short and long pile (Fig. F.7 and F.11, Appendix F). For the variable k, the values for COV(Y_{Top}) is little higher for fixed head long pile than the short pile (Fig. F.9, Appendix F).

If we compare the boundary condition then free head long pile has lower values of $COV(Y_{Top})$ for COV(B) and COV(C) than fixed head long pile, but shows the same kind of pattern. All the other variables show approximately same kind of pattern and values for $COV(Y_{Top})$. In descending order, variables affecting $COV(Y_{Top})$: C→ EI→ B→ ε_{50}→ k→ γ' (Fig. 6.8).

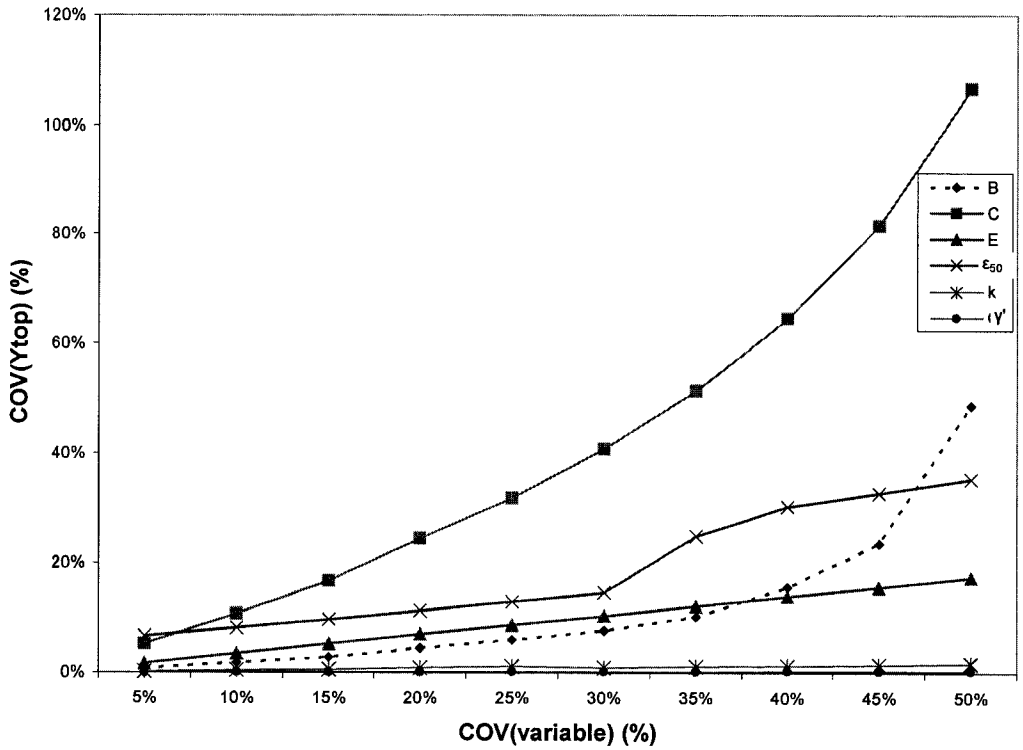


Fig. 6.8 Effect of different variables on $COV(Y_{Top})$ in fixed head single long (10T) pile at the optimum lateral load of 305.25 kN.

In case of $COV(M_{Max})$, fixed head long pile is less steeper than fixed head short pile for COV(B) and COV(C) (Fig. F.2 and F.4, Appendix F). For the variable ε_{50}, fixed head long pile has lower value of $COV(M_{Max})$ then fixed head short pile (Fig. F.6, Appendix F). For variables EI and γ', the values and pattern is almost similar for both

cases i.e. fixed head short and long pile (Fig. F.8 and F.12, Appendix F). For the variable k, the values for COV(M_{Max}) is little higher for fixed head long pile than the short pile (Fig.F.10, Appendix F).

Fixed head long pile has steeper curve between COV(M_{Max}) and COV(B) or COV(C) than free head long pile. The values for COV(M_{Max}) connected with COV(γ') are higher in fixed head long pile. Table 6.4 shows the variability of COV(Y_{Top}) and COV(M_{Max}) with the variation of random variable.

Table 6.4 Values of COV(Y_{Top}) and COV(M_{Max}) for different random variable in fixed head single long (10T) pile.

Random Variable	COV (Variable) (%)	Max. COV(Y_{Top}) (%)	Max. COV(M_{Max}) (%)
C	0-50%	0 - 106.7%	0 - 28.53%
EI	0-50%	0 - 42.9%	0 - 7.06%
ε50	0-50%	0 - 20.5%	0 - 8.2%
B	0-50%	0 - 48.7%	0 - 13.11%
k	0-50%	0 - 1.7%	0 - 0.6%
γ'	0-50%	0 - 0.85%	0 - 0.37%

6.4.3 Discussion on the reliability analysis of fixed head single long (10T) pile

Fixed head long pile is safer than fixed head short pile (Section 6.3.3) as well as free head long pile (Section 6.2.3) with higher reliability index (β_{Ytop}) especially for the lateral load 375 kN (Fig. F.17-F.22, Appendix F). Fixed head short pile was failing at top due to extreme deflection at 375 kN with $\beta_{Ytop}<2$. Fixed head long pile fails at top due to extreme deflection ($\beta_{Ytop}<2$)when COV(B) is greater than 30% for lateral load 375 kN or

COV(C) is greater than 45% for load 305.25 kN, >25% for load 340 kN, or >10% for load 375 kN. It also fails at top due to extreme deflection (β_{Ytop}<2), if COV(EI) >30% for lateral load 375 kN. In descending order, variables affecting β_{Ytop}: C→ EI→ B→ ε_{50}→ k→ γ' (Fig. F.13-F.16, Appendix F).

Compared to fixed head short pile, fixed head long pile has little higher values of β_{Mmax}, but still it is lower than 3.7 for all four lateral loads. Hence fixed head is more vulnerable to fail by bending moment (M_{Max}) than free head. In descending order, random variables affecting β_{Mmax} : C→ B→ EI→ ε_{50}→ k→ γ' (Fig. F.27 – F.32, Appendix F).

6.5 Discussion on the results of laterally loaded hinged head long (10T) pile group with spacing (3D)

The response of a laterally loaded pile within a group of closely spaced piles is different than the response of a single isolated pile. The pile group used for the analysis is formed of 9 long piles (Fig. 3.5, Chapter 3) with center to center spacing of 3D.

The boundary condition hinged head is similar to the free head boundary condition. The only difference is that the hinged head boundary condition is used in case of pile group while the free head boundary condition is used for the single isolated pile. Both kinds of boundary condition provide same kind of restraint at pile head.

6.5.1 Relationship between p-y curve and lateral load at pile cap

The deflection and bending moment obtained in free head single pile can be obtained in a pile of closely spaced pile group at lower lateral load per pile. For example, to get a pile head deflection of 0.0047 m, 132 kN is applied to free head single long pile,

while only 90.78 kN of lateral load per pile (90.78 x 9 = 817 kN) needed to get same deflection (Fig. 6.9) in hinged head pile group (3D). It happens because of pile-soil-pile interaction, and lateral resistance provided by pile cap. Above phenomena is also discussed by R.L. Mokwa and J.M. Duncan in their paper "Laterally loaded pile group effects and p-y multipliers". They also mentioned that the piles in a group carry unequal lateral loads, depending on their location within the group and the spacing between piles. Fig. 6.9 clearly confirms that for a applied lateral load of 817 kN, pile C in leading row carry highest load of 100 kN then comes the pile B of first subsequent row with 90 kN, and at the end pile A of second subsequent row with 82 kN. This unequal distribution of load among piles is caused by shadowing effect. It is term used to describe the overlap of zones of resistance, and the consequential reduction of lateral soil resistance.

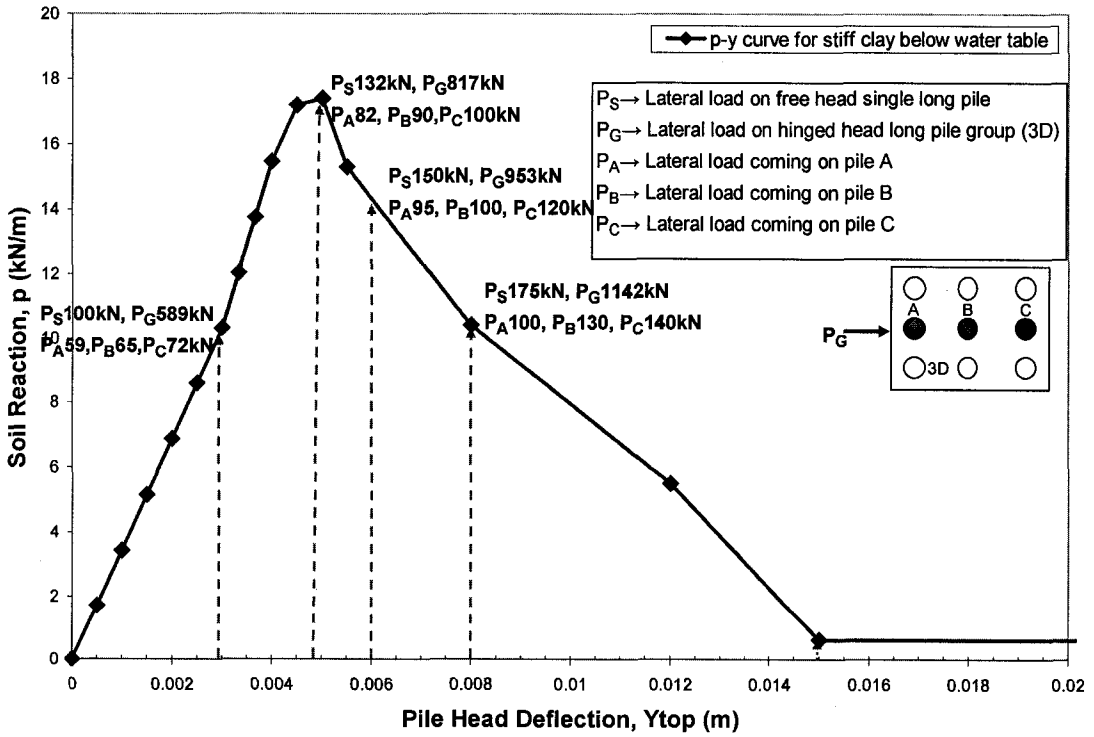


Fig. 6.9 Lateral loads presenting the pile-soil-pile interaction and shadowing effect in hinged head long pile group with spacing (3D).

6.5.2 Discussion on the probabilistic modeling of hinged head long (10T) pile group with spacing (3D)

$COV(Y_{Top})$ connected to COV(B) for hinged head long pile group (3D) is almost similar in value and little different in curve pattern with the $COV(Y_{Top})$ connected to COV(B) for hinged head single long pile (Fig. G.1, Appendix G). In case of $COV(\varepsilon_{50})$ and COV(EI) for hinged head long pile group (3D), lateral load does not have very prominent effect on $COV(Y_{Top})$ (Fig. G.5 and G.7, Appendix G). The curve between COV(EI) and $COV(Y_{Top})$ is very different for hinged head pile group (3D) than for the free head single pile. $COV(Y_{Top})$ connected to COV(k) for hinged head pile group (3D) has higher values than for free head single long pile.

$COV(M_{Max})$ connected to COV(B), COV(C), $COV(\varepsilon_{50})$, and COV(EI) for the pile C (leading row) of hinged head long pile group (3D) is way lower than $COV(M_{Max})$ for free head single long pile (Fig. G.2(a),G.4(a),G.6(a),G.8(a), Appendix G). $COV(M_{Max})$ connected to COV(k) and $COV(\gamma')$ for the pile C of hinged head long pile group (3D) is negligible (Fig. G.10, G.12, Appendix G). If we compare the piles in leading, first trailing, and second trailing row for $COV(M_{Max})$, than middle row i.e. first trailing row has lower $COV(M_{Max})$ connected to COV(B), $COV(\varepsilon_{50})$, COV(EI), and COV(k) than the piles of other two rows (Fig. G.2(b),G.4(b),G.6(b),G.8(b), Appendix G). Table 6.5 shows the variability of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of random variable.

Table 6.5 Values of COV(Y_{Top}) and COV(M_{Max}) for different random variable in hinged head long (10T) pile group with spacing (3D)

Random Variable	COV(Variable) (%)	Max. COV(Y_{Top}) (%)	Max. COV(M_{Max}) (%)
C	0-50%	0 - 81.12%	0 - 17.10%
EI	0-50%	0 - 37.3%	0 - 1.35%
ε50	0-50%	0 - 19.73%	0 - 1.3%
B	0-50%	0 - 26.01%	0 - 8.66%
k	0-50%	0 - 1.82%	0 - 0.21%
γ'	0-50%	0 - 0.44%	0 - 0.05%

6.5.3 Discussion on the reliability analysis of hinged head long (10T) pile group with spacing (3D)

Reliability index connected to Y_{Top} (β_{Ytop}) for hinged head long pile group (3D) (Fig. G.17-G.22, Appendix G) is same as (β_{Ytop}) for free head single long pile (section 6.2.3).The β_{Ytop} connected to COV of all six variables is less than 2 for lateral load 1142 kN. In descending order, variables affecting β_{Ytop}: C→ EI→ ε_{50}→ B→ k→ γ' (Fig. G.13-G.16, Appendix F).

Reliability index connected to M_{Max} (β_{Mmax}) for pile C (leading row) hinged head long pile group (3D) (Fig. G.17-G.22, Appendix G) is same as (β_{Mmax}) for free head single long pile (section 6.2.3). In descending order, variables affecting β_{Mmax}: C→ B→ ε_{50}→ EI→ k→ γ' (Fig. G.23-G.26, Appendix G).

6.6 Discussion on the results of laterally loaded fixed head long (10T) pile group with spacing (3D)

6.6.1 Relationship between p-y curve and lateral load at pile cap

The deflection and bending moment obtained in fixed head single pile can be obtained in a pile of closely spaced fixed head pile group at lower lateral load per pile. For example, to get a pile head deflection of 0.005 m, 305.25 kN is applied to fixed head single long pile, while only 203.55 kN of lateral load per pile (203.55 x 9 piles = 1832 kN) needed to get same deflection (Fig. 6.10) in fixed head pile group (3D). Also pile in a fixed head pile group carry different lateral load. For a lateral load of 1832 kN acting on pile cap, leading row's pile C carry 230 kN, first subsequent row's pile B carry 200 kN, and second subsequent row's pile A carry 180 kN (Fig. 6.10). Also higher lateral load (for example 1832 kN) needs to be applied to fixed head long pile group (3D) than free head long pile group (3D) (for example 817 kN) to get the same deflection (i.e. 0.005 m).

6.6.2 Discussion on the probabilistic modeling of fixed head long (10T) pile group with spacing (3D)

The pattern and values of curve for $COV(Y_{Top})$ connected to the COV of variables B, C, ε_{50}, γ', k for fixed head long pile group (3D) is very close to $COV(Y_{Top})$ for fixed head single long pile (Fig. H.1, H.3, H.5, H.9, H.11, Appendix H). The pattern of curve for $COV(Y_{Top})$ connected to the COV(EI) for fixed head long pile group is different from that of fixed head single long pile (Fig. H.7).

The pattern is different and the value is higher for COV(Y_{Top}) connected to the COV(B) for fixed head long pile group than that of hinged head long pile group. COV(Y_{Top}) connected to variables C, ε_{50}, γ', k is almost same for both cases.

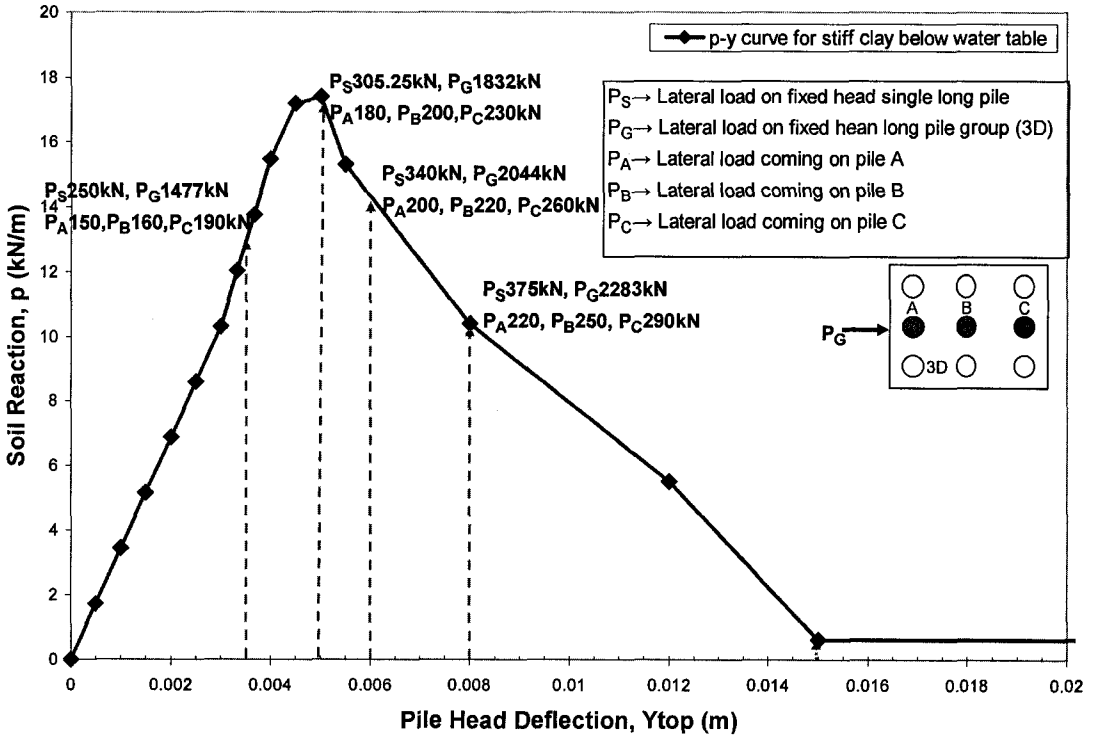


Fig. 6.10 Lateral loads presenting the pile-soil-pile interaction and shadowing effect in fixed head long pile group with spacing (3D).

The pattern and values of curve for COV(M_{Max}) connected to the COV of variables B, γ' for pile C of fixed head long pile group (3D) is very close to COV(M_{Max}) for fixed head single long pile (Fig. H.2(a), H.12(a), Appendix H). COV(M_{Max}) connected to variables C, ε_{50}, EI has a different pattern in pile C of fixed head pile group than fixed single long pile. The COV(M_{Max}) connected to the COV of variables B, C, ε_{50}, EI, γ' for pile C (leading row) of fixed head long pile group (3D) is very high compared to pile C of

hinged head pile group (3D) (Fig. H.2, H.4, H.6, H.8, H.12, Appendix H). Pile in leading, first subsequent and second subsequent rows are behaving alike for $COV(M_{Max})$ connected to variables B, C, EI, γ' (Fig. H.2(b), H.4(b), H.8(b), H.12(b), Appendix H) Table 6.6 shows the variability of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of random variable.

Table 6.6 Values of $COV(Y_{Top})$ and $COV(M_{Max})$ for different random variable in fixed head long (10T) pile group with spacing (3D)

Random Variable	COV(Variable) (%)	Max. $COV(Y_{Top})$ (%)	Max. $COV(M_{Max})$ (%)
C	0-45%	0 - 97.26%	0 - 28.47%
EI	0-50%	0 - 31.45%	0 - 11.46%
ε50	0-50%	0 -20.5%	0 - 6.26%
B	0-30%	0 - 38.13%	0 - 10.03%
k	0-50%	0 - 0.3%	0 - 0.61%
γ'	0-50%	0 - 0.3%	0 - 0.27%

6.6.3 Discussion on the reliability analysis of fixed head long (10T) pile group with spacing (3D)

Reliability index (β_{Ytop}) is approximately same for fixed head long pile group (3D) and fixed head single long pile (Fig. H.17-H.22, Appendix H). In descending order, variables affecting β_{Ytop} in fixed head long pile group (3D): C→ B→ EI→ ε_{50}→ k→ γ' (Fig. H.13-H.16, Appendix H). Reliability index (β_{Ytop}) is higher (specially for 4^{th} load) for the fixed head long pile group than the hinged head long pile group (3D).

Reliability index connected to M_{Max} (β_{Mmax}) is higher for pile C in fixed head pile group than the fixed head single pile (Fig. H.27- H.32, Appendix H). Also the fixed head long pile group is safe against M_{Max} with (β_{Mmax})>3.7 for all six variables under all four lateral loads. In descending order, variables affecting β_{Mmax} in pile C of fixed head long pile group (3D): C→ B→ EI→ ε_{50}→ k→ γ' (Fig. H.23-H.26, Appendix H). The values for β_{Mmax} is higher for pile C of fixed head pile group (3D) than pile C of hinged head pile group (3D) (section 6.5.3).

6.7 Discussion on the results of laterally loaded hinged head long (10T) pile group with spacing (4D)

6.7.1 Relationship between p-y curve and lateral load at pile cap

In addition to the points discussed in section 6.5.1, spacing between the piles in pile group also influence the lateral load applied at pile cap to get the specific deflection. Results shows that higher lateral load (for example 898 kN) (Fig. 6.11) needs to be applied to pile cap in hinged head pile group with spacing between pile 4D hinged free head pile group with pile spacing 3D (for example 817 kN) to get some specific pile head deflection (for example 0.005 m).

6.7.2 Discussion on the probabilistic modeling of hinged head long (10T) pile group with spacing (4D)

The values and pattern of the curves between COV(Y_{Top}) and COV of all 6 variables is just about same for hinged head pile group with pile spacing 3D (section 6.5.2) and pile spacing 4D (Fig. I.1, I.3, I.5, I.7, I.9, and I.11, Appendix I). It indicates

that pile spacing affects the pile head/cap deflection for given lateral load but it does not affect the COV(Y_{Top}).

In case of COV(M_{Max}) connected to all 6 variables, results show that the values are lower for pile C of hinged head pile group (4D) than the pile C of hinged head pile group with pile spacing 3D (Fig. I.2, I.4, I.6, I.8, I.10, I.12, Appendix I). Behavior of piles in three rows towards the COV(M_{Max}) in hinged head long pile group (4D) is same as of hinged head pile group with pile spacing 3D (section 6.5.2). Table 6.7 shows the variability of COV(Y_{Top}) and COV(M_{Max}) with the variation of random variable.

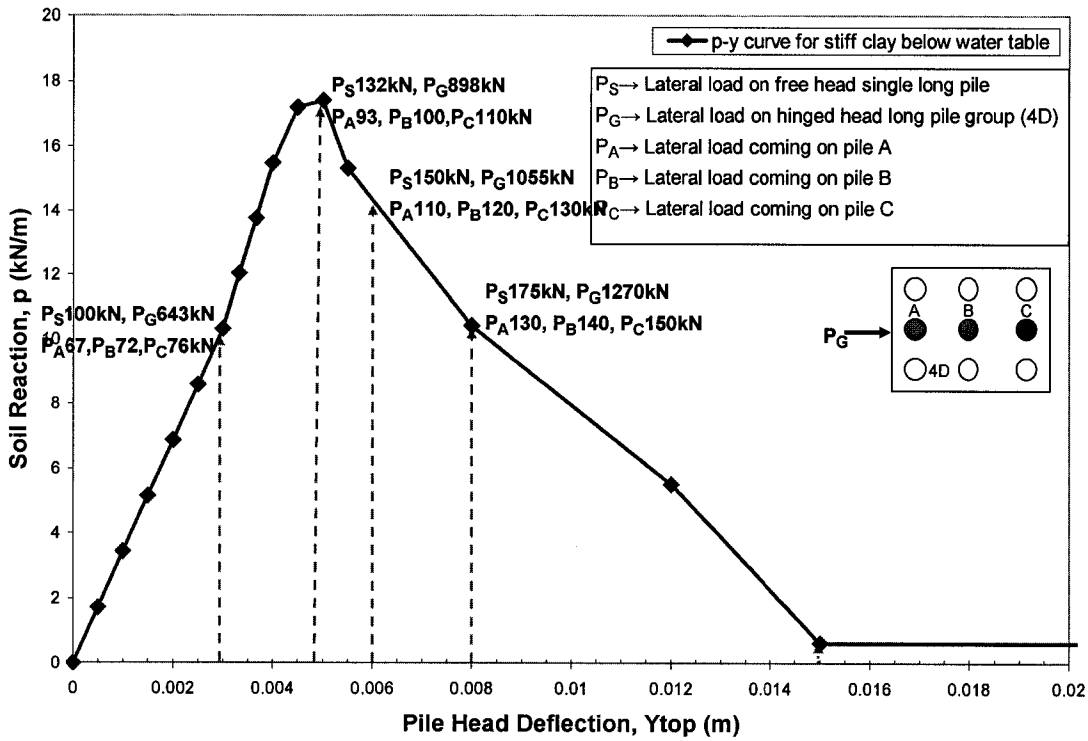


Fig. 6.11 Lateral loads presenting the pile-soil-pile interaction, shadowing effect, and the spacing influence in hinged head long pile group with spacing (4D).

Table 6.7 Values of $COV(Y_{Top})$ and $COV(M_{Max})$ for different random variable in hinged head long (10T) pile group with spacing (4D)

Random Variable	COV(Variable) (%)	Max. $COV(Y_{Top})$ (%)	Max. $COV(M_{Max})$ (%)
C	0-50%	0 - 75.91%	0 - 14.5%
EI	0-50%	0 - 40.9%	0 - 0.21%
ε50	0-50%	0 -19.2%	0 - 0.4%
B	0-50%	0 - 46.24%	0 - 4.12%
k	0-50%	0 - 2.15%	0 - 0.35%
γ'	0-50%	0 - 0.44%	0 - 0.04%

6.7.3 Discussion on the reliability analysis of hinged head long (10T) pile group with spacing (4D)

Reliability index connected to Y_{Top} (β_{Ytop}) for hinged head pile group with spacing 4D (Fig. I.17-I.22, Appendix I) is similar to that of hinged head pile group with spacing 3D (section 6.5.3). It signifies that change of pile spacing from 3D to 4D does not affect (β_{Ytop}). Also, β_{Ytop} is less than 2 at the fourth load for all six variables. In descending order, variables affecting β_{Ytop} in hinged head long pile group (4D): C→ EI→ ε_{50}→ B→ k→ γ' (Fig.I.13-I.16, Appendix I).

Even reliability index connected to M_{Max} (β_{Mmax}) is similar for pile C of hinged head long pile group with spacing 4D and spacing 3D (Fig. I.27-I.32, Appendix I). In descending order, variables affecting β_{Mmax} in hinged head long pile group (4D): C→ B→ EI→ ε_{50}→ k→ γ' (Fig. I.23-I.26, Appendix I).

6.8 Discussion on the results of laterally loaded fixed head long (10T) pile group with spacing (4D)

6.8.1 Relationship between p-y curve and lateral load at pile cap

Points discussed in Section 6.7.1 for hinged head pile group are also true for fixed head pile group. Lateral load of 2138 kN is applied at pile cap for fixed head pile group of spacing 4D to get a pile head deflection of 0.005 m (Fig. 6.12). Whereas in fixed head pile group with spacing 3D, same pile head deflection is obtained at lower load i.e. 1832 kN (Section 6.6.1). Fig. 6.12 also proves the point which is mentioned in earlier sections that fixed head pile group needs higher lateral load than hinged head pile group to get same deflection.

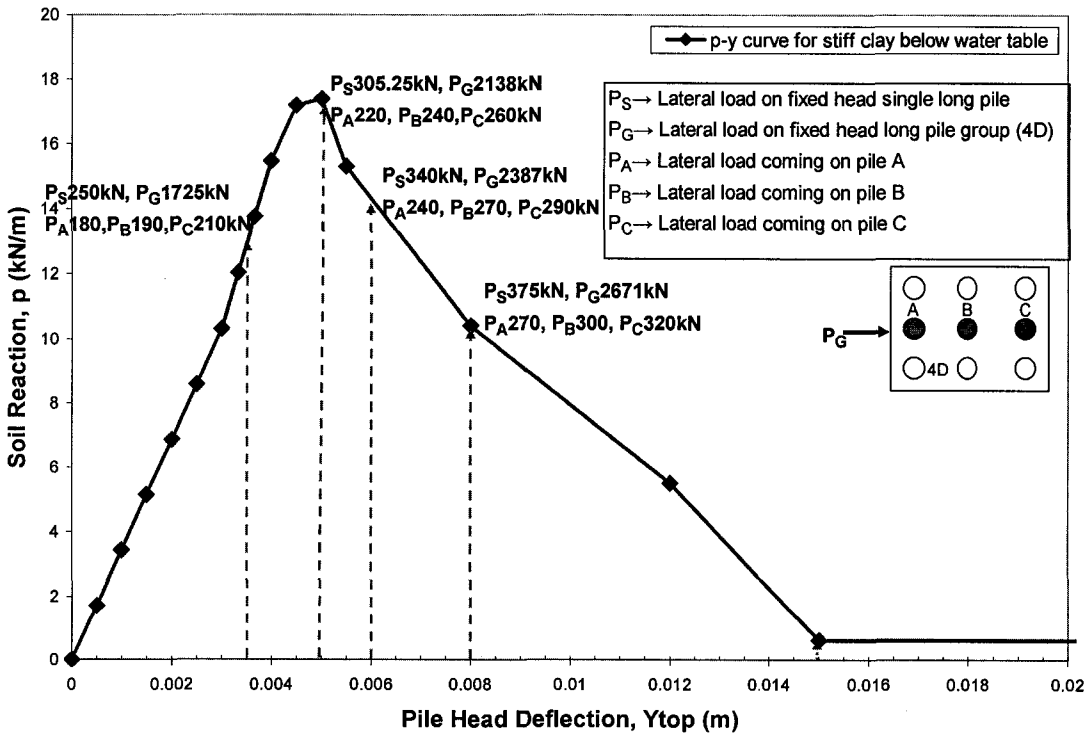


Fig. 6.12 Lateral loads presenting the pile-soil-pile interaction, shadowing effect, and the spacing influence in fixed head long pile group with spacing (4D).

6.8.2 Discussion on the probabilistic modeling of fixed head long (10T) pile group with spacing (4D)

For $COV(Y_{Top})$, all variables in fixed head pile group (4D) (Fig. J.1, J.3, J.5, J.7, J.9, J.11, Appendix J) are behaving similarly as variables in fixed head pile group (3D) (section 6.6.2). The COV of B, C, and k has lower value of $COV(Y_{Top})$ for fixed head pile group (4D) than hinged head pile group (4D) (section 6.7.2).

For $COV(M_{Max})$, all variables except variable k in pile C of fixed head pile group (4D) (Fig. J.2(a), J.4(a), J.6(a), J.8(a), J.12(a), Appendix J) are behaving similar to variables in pile C of fixed head pile group (3D). Piles of leading row, first subsequent row, and second subsequent row for fixed head pile group of spacing 4D (Fig. J.2(b), J.4(b), J.6(b), J.8(b), J.12(b), Appendix J) is performing the same way as of piles of fixed head pile group of spacing 3D. $COV(M_{Max})$ for all six variables has higher value for pile C of fixed head pile group (4D) than pile C of hinged head pile group (4D). Table 6.8 shows the variability of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of random variable.

Table 6.8 Values of $COV(Y_{Top})$ and $COV(M_{Max})$ for different random variable in fixed head long (10T) pile group with spacing (4D)

Random Variable	COV(Variable) (%)	Max. $COV(Y_{Top})$ (%)	Max. $COV(M_{Max})$ (%)
C	0-45%	0 - 99.32%	0 - 29.5%
EI	0-50%	0 - 37%	0 - 9.63%
ε50	0-50%	0 -20.5%	0 - 6.53%
B	0-40%	0 - 48.03%	0 - 19.94%
k	0-50%	0 - 0.28%	0 - 0.59%
γ'	0-50%	0 - 0.4%	0 - 0.33%

6.8.3 Discussion on the reliability analysis of fixed head long (10T) pile group with spacing (4D)

Reliability index connected to Y_{Top} (β_{Ytop}) and to the M_{Max} (β_{Mmax}) for fixed head pile group with spacing 4D (Fig. J.17-J.22, and J.27-J.32, Appendix J) is similar to that of fixed head pile group with spacing 3D (section 6.6.3). It signifies that change of pile spacing from 3D to 4D does not affect (β_{Ytop}). In descending order, variables affecting β_{Ytop} in fixed head long pile group (4D): C→ B→ EI→ ε_{50}→ k→ γ' (Fig. J.13-J.16, Appendix J). Reliability index connected to Y_{Top} (β_{Ytop}) and to the M_{Max} (β_{Mmax}) is little higher in case of fixed head pile group (4D) than hinged head pile group (4D). In descending order, variables affecting β_{Mmax} in pile C of fixed head long pile group (4D): C→ B→ EI→ ε_{50}→ k→ γ' (Fig. J.23-J.26, Appendix J).

6.9 Discussion on the results of laterally loaded hinged head long (10T) pile group with spacing (5D)

6.9.1 Relationship between p-y curve and lateral load at pile cap

A paper by R. L. Mokwa and J. M. Duncan called "Laterally loaded pile group effects and p-y multipliers" points out that group effects are small when center-to-center pile spacing parallel to load exceeds 6D. If we compare Figure 6.9, 6.11, and 6.13, it is clear that as the pile spacing is increasing from 3D to 5D, the load distribution in pile A (P_A), pile B (P_B), and pile C (P_C) is getting closure to the lateral load on single pile (P_S).

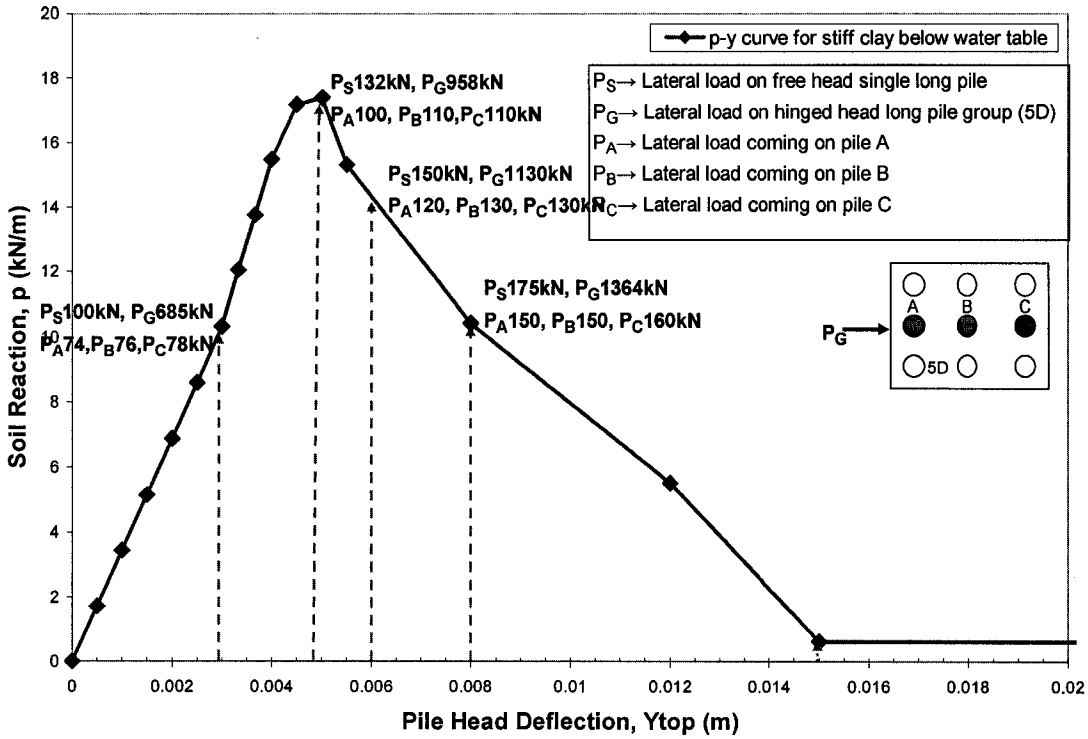


Fig. 6.13 Lateral loads presenting the pile-soil-pile interaction, shadowing effect, and the spacing influence in hinged head long pile group with spacing (5D).

6.9.2 Discussion on the probabilistic modeling of hinged head long (10T) pile group with spacing (5D)

From the comparison of all the result related to $COV(Y_{Top})$ in hinged head pile groups, it is very clear that variation of center-to-center pile spacing from 3D to 5D (Appendix K), do not cause any significant change in $COV(Y_{Top})$ connected to all six random variables. In case of M_{Max}, the values for $COV(M_{Max})$ are going down for variable B, EI, k, and ε_{50} when we change pile spacing in hinged head pile group from 3D to 5D. Also the performance of piles in leading, first subsequent, and second subsequent row for variables B, C, ε_{50}, γ' do not change when pile spacing vary from 3D to 5D (Appendix K). Table 6.9 shows the variability of $COV(Y_{Top})$ and $COV(M_{Max})$ with the variation of random variables.

Table 6.9 Values of COV(Y_{Top}) and COV(M_{Max}) for different random variable in hinged head long (10T) pile group with spacing (5D)

Random Variable	COV(Variable) (%)	Max. COV(Y_{Top}) (%)	Max. COV(M_{Max}) (%)
C	0-50%	0 - 74.34%	0 - 12.53%
EI	0-50%	0 - 41.66%	0 - 0.08%
ε50	0-50%	0 -19%	0 - 0.16%
B	0-50%	0 - 39.71%	0 - 1.25%
k	0-50%	0 - 2.32%	0 - 0.17%
γ'	0-50%	0 - 0.44%	0 - 0.03%

6.9.3 Discussion on the reliability analysis of hinged head long (10T) pile group with spacing (5D)

Comparison of the results related to reliability index connected to Y_{Top} (β_{Ytop}) points out that variation of pile spacing from 3D to 5D (Appendix K) has no effect on the (β_{Ytop}) for hinged head pile group; whereas in case of reliability index connected to M_{Max} (β_{Mmax}), hinged head pile group becomes more vulnerable to failure from M_{Max} as pile spacing increases from 3D to 5D (Appendix K).

6.10 Discussion on the results of laterally loaded fixed head long (10T) pile group with spacing (5D)

6.10.1 Relationship between p-y curve and lateral load at pile cap

Points we discussed in section 6.9.1 are true for Section 6.10.1. For example, to get a pile head deflection of 0.005 m, 305.25 kN (P_S) of lateral load is applied to fixed head single long pile. Lateral load distribution in pile C (P_C), to get defection of 0.005 m, is 230 kN (Fig. 6.10) for 3D, 260 kN (Fig. 6.12) for 4D, and 270 kN (Fig. 6.14) for 5D. It

shows clearly that as pile spacing is increasing, P_C is getting closure to P_S. That means group effect is diminishing.

6.10.2 Discussion on the probabilistic modeling of fixed head long (10T) pile group with spacing (5D)

Same as the case with hinged head pile group (Section 6.9.2), $COV(Y_{Top})$ in fixed head pile group for all variables stay almost same as pile spacing changes from 3D to 5D (Appendix L). For $COV(M_{Max})$ in fixed head pile group, the value remains just about the same for all variables except B when pile spacing in the direction of load changes from 3D to 5D (Appendix L).

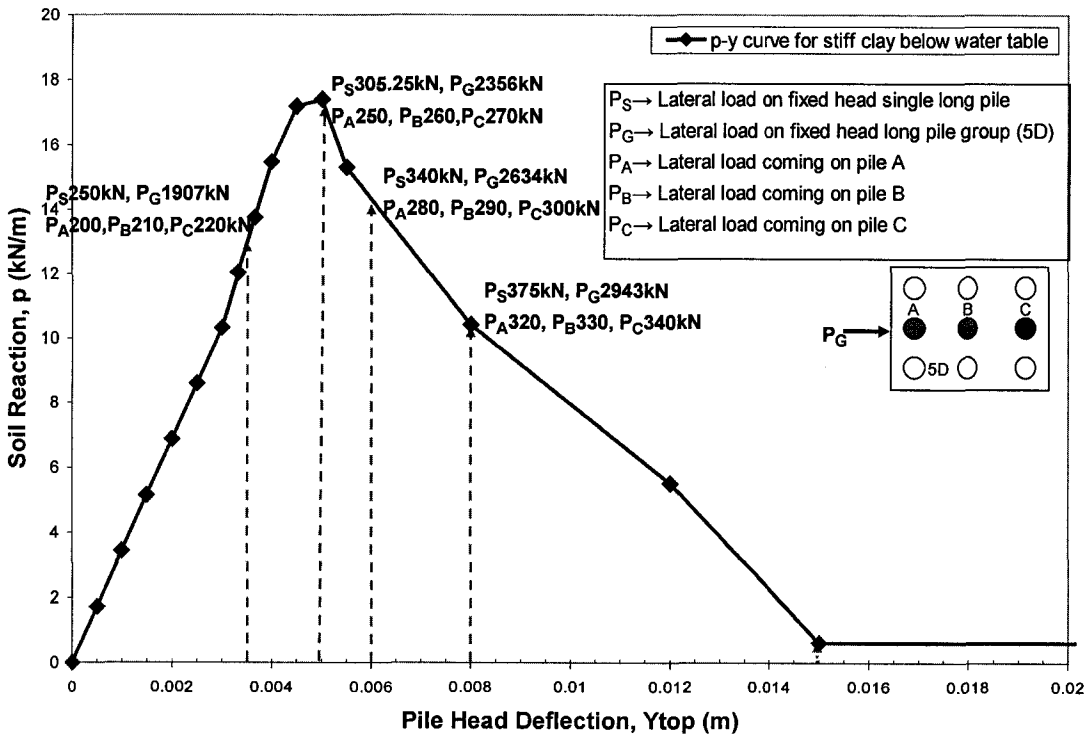


Fig. 6.14 Lateral loads presenting the pile-soil-pile interaction, shadowing effect, and the spacing influence in fixed head long pile group with spacing (5D).

Table 6.10 shows the variability of COV(Y_{Top}) and COV(M_{Max}) with the variation of random variable.

Table 6.10 Values of COV(Y_{Top}) and COV(M_{Max}) for different random variable in fixed head long (10T) pile group with spacing (5D)

Random Variable	COV(Variable) (%)	Max. COV(Y_{Top}) (%)	Max. COV(M_{Max}) (%)
C	0-50%	0 - 100.27%	0 - 29.85%
EI	0-50%	0 - 38.94%	0 - 9.04%
ε50	0-50%	0 -20.62%	0 - 6.08%
B	0-40%	0 - 33.04%	0 - 12.78%
k	0-50%	0 - 0.424%	0 - 0.86%
γ'	0-50%	0 - 0.34%	0 - 0.29%

6.10.3 Discussion on the reliability analysis of fixed head long (10T) pile group with spacing (5D)

Reliability index connected to Y_{Top} (β_{Ytop}) stays approximately same as pile spacing is changing from 3D to 5D (Appendix L). Reliability index connected to Y_{Top} (β_{Ytop}) is higher for fixed head pile group than for hinged head pile group, especially for the fourth load (Appendix L), whereas reliability index connected to M_{Max} (β_{Mmax}), pile C of fixed head pile group becomes more vulnerable to failure from M_{Max} as pile spacing increases from 3D to 5D (Appendix L). Reliability index connected to M_{Max} (β_{Mmax}) is higher for pile C (leading row) in fixed head pile group than hinged head pile group.

6.11 Combined load analysis on free head long (10T) pile

As discussed in Chapter 5, combined load analysis is carried out on free head long (10T) pile by considering four scenarios. In the first scenario, lateral load (P) is applied at pile head. In second scenario, instead of lateral load, bending moment (M) is applied at pile head. P and M vary in a discrete fashion. In the third scenario, the results of first two scenarios are superimposed linearly. In the last scenario both P and M are applied together to the free head long pile.

In this analysis the applied load P and M are considered as random variables and analyzed the same way as we analyzed other variables (B, C, EI, ε_{50}, k, γ') in previous section. The probabilistic modeling and reliability analysis is carried out to get COV and reliability index connected to serviceability (Y_{Top}).

6.11.1 Scenario I: lateral load (P) applied to free head single long pile

In this scenario, lateral load (P) is varied in discrete fashion and all the other variables (B, C, EI, ε_{50}, k, γ') are kept at their respective mean values. This analysis is conducted to figure out a relation between varying lateral load, P and pile head deflection, Y_{Top}. From Fig. 6.15 it is clear that up to the lateral of 40 kN, the relationship between P and Y_{Top} is linear and after that it gets nonlinear (Appendix M).

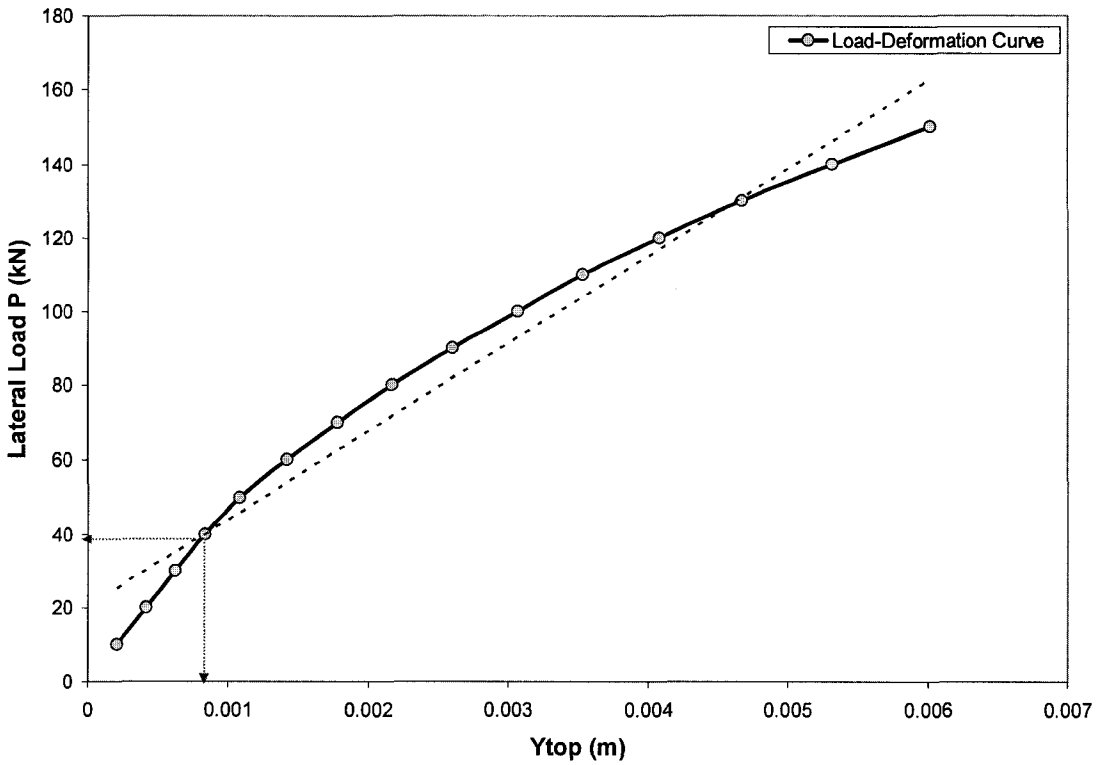


Fig. 6.15 Relationship between lateral load P and the pile head deflection Y_{Top}.

6.11.2 Scenario II: Bending moment (M) applied to free head single long pile

Similar to the scenario I, in scenario II, bending moment M is taken as random variable and is varied discretely. Analysis is conducted by keeping all the other variables at their mean value to obtain the relationship between applied bending moment M and pile head deflection Y_{Top}. Fig. 6.16 noticeably shows that the relation is linear up to 52 kN.m and after that it gets non-linear (Appendix M).

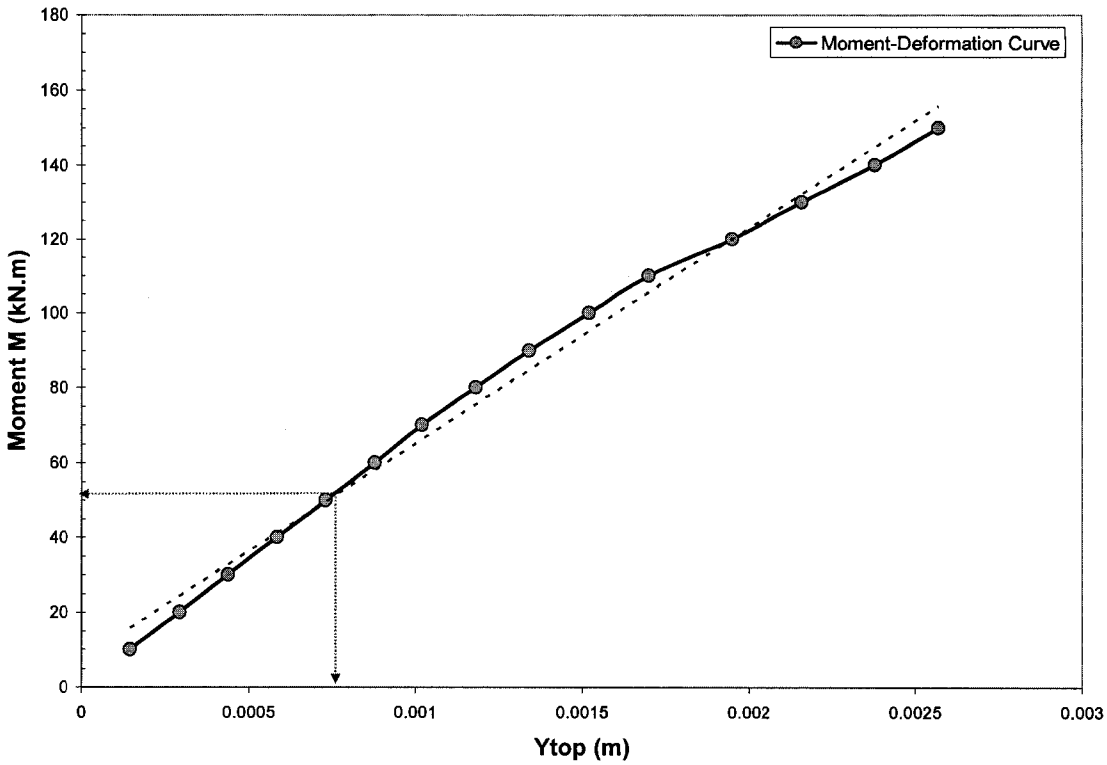


Fig. 6.16 Relationship between bending moment M and the pile head deflection Y_{Top}.

6.11.3 Scenario III: Superimposition of first two scenarios on free head long pile

Superimposition of the results of first two scenarios is considered as linear system. To conduct this study, lateral load P and bending moment M is chosen in such a way that they both give the same deflection individually. For this study the mean value chosen for P is 32 kN and mean value for M is 45 kN.m. They both give a pile head deflection of 0.00065 m individually. For scenario III both are varied by + and -5% from their mean value and the resulting pile head deflection is superimposed i.e. $\mathbf{2Y_{Top}}$. After that probabilistic modeling and reliability analysis is carried out to get $COV(Y_{Top}{}^{L})$ and reliability index (β_L) (Appendix M).

6.11.4 Scenario IV: Lateral load P and Bending moment M applied to free head long pile

Instead of superimposing the results of first two scenarios, in this case both lateral load P and bending moment M are applied together at pile head and Y_{Top} is calculated. This system is considered as nonlinear. Alike the scenario III, P and M is varied by 5% and applied to pile head to get Y_{Top}. After that probabilistic modeling and reliability analysis were conducted (Appendix M).

6.11.5 Comparison of results of scenario III and IV

Fig. M.3 (Appendix M) clearly shows that up to P equals to 32 kN and M equals to 45 kN.m, both curves i.e. linear load+moment-deformation curve and nonlinear load+moment-deformation curve are coinciding and after that nonlinear curve starts leaning down with higher pile head deflection than linear curve for the same load.

Results illustrate that $COV(Y_{Top})$ for non-linear system is higher than linear system (Fig. M.4, Appendix M). As we know that reliability index is the inverse of COV. Thus reliability index connected to Y_{Top} is higher for linear system (β_L) than for non-linear system (β_{NL}) (Fig. M.5, Appendix M). Results also show that the difference between the reliability index of serviceability of linear and nonlinear system widens as the COV(combined load) increases . The value of β_L and β_{NL} is greater 2, means the tip or pile head of pile is safe against the failure from serviceability.

CHAPTER 7

CONCLUSIONS FROM STUDY

A comprehensive study was performed on laterally loaded single pile and pile group embedded in stiff clay below water table, to judge the affect of uncertainty connected to surrounding soil, pile material, and applied load on the performance of pile structure. Performance of laterally loaded pile or pile group is checked in terms of ultimate limit state and serviceability limit state. Reliability analysis is used to get a systematic account of the uncertainties linked with pile material, soil, and applied lateral load. Different aspects of piles are considered in this study such as length of pile, boundary condition at pile head, and center-to-center spacing between piles in pile group.

An extensive discussion is carried out on the results of probabilistic modeling and reliability analysis to figure out the important aspects on the performance of laterally loaded single pile or pile group. The important points which came out of the discussion are inscribed in this chapter.

7.1 Conclusion on laterally loaded single pile

Following are the important points noticed on the behavior of laterally loaded single pile:

1. Increase in the length of pile from 3T to 10T, causes very minute change in pile head deflection at some given lateral load. This is true for free head as well as fixed head pile.
2. In contrary to length, boundary condition makes a large difference in deflection at pile head. To get the same pile head deflection as of free head pile, fixed head pile must be loaded laterally with more than 2 times the load. This is true for short (3T) as well as for long (10T) pile.
3. For some specific value of COV(Random variable), $COV(Y_{Top})$ is higher for higher lateral load. Only exception is the variable ε_{50}. The $COV(Y_{Top})$ is decreasing as lateral load increases at some specific value of $COV(\varepsilon_{50})$.
4. Same as the case with $COV(Y_{Top})$, $COV(M_{Max})$ is also growing as the lateral load goes higher. Only exception are the variables ε_{50} and EI.
5. In descending order, the variables affecting $COV(Y_{Top})$ in free and fixed head single pile: C→ EI→ ε_{50}→ B→ k→ γ'. Affect of variable γ' on $COV(Y_{Top})$ is almost negligible. The $COV(Y_{Top})$ gets more sensitive to variable B, when COV(B) crosses 30% mark.
6. For $COV(M_{Max})$, only random design variable 'C' is showing considerable influence. All other variables B, EI, ε_{50}, k, γ' cause comparatively small change. Especially, affect of random variables k and γ' is negligible. It means maximum bending moment of laterally loaded pile is not affected by variables k and γ'.
7. In descending order, the variables affecting $COV(M_{Max})$ in free and fixed head single pile: C→ EI→ ε_{50}→ B→ k→ γ'. The $COV(M_{Max})$ gets more sensitive to variable B, when COV(B) crosses 30% mark.

8. Instead of the vast difference in the length of free head short (3T) and free head long pile (10T), results of probabilistic modeling {COV(Y_{Top}) and COV(M_{Max})} indicate that the pattern and values are almost similar in both cases for all 6 random design variables.
9. When the length is increased from 3T to 10T, the curve between COV(B) or COV(C) and COV(Y_{Top}) gets less steep (Fig.F.1 and F.3, Appendix F) for fixed head pile. It means the structure is comparatively less vulnerable to failure.
10. In case of COV(M_{Max}), fixed head long pile is less steeper than fixed head short pile for COV(B) and COV(C) (Fig. F.2 and F.4, Appendix F). For the variable ε_{50}, fixed head long pile has lower value of COV(M_{Max}) then fixed head short pile.
11. If we compare the boundary condition then free head long pile has lower values of COV(Y_{Top}) for COV(B) and COV(C) than fixed head long pile, but shows the same kind of pattern. All other variables show approximately same kind of pattern and values for COV(Y_{Top}).
12. Fixed head long pile has steeper curve between COV(M_{Max}) and COV(B) or COV(C) than free head long pile.
13. Compared to free head short pile, fixed head short (3T) pile COV(Y_{Top}) is rising very rapidly as COV(B) and COV(C) increases at the rate of 5%. All the other random variables are behaving in almost the same manner (with little higher value of COV(Y_{Top})) as in free head short pile.
14. In fixed head short pile COV(M_{Max}) is showing the same pattern with COV(B) and COV(C) as COV(Y_{Top}) but with 1/3 values. Also COV(M_{Max}) connected

with other variables (EI, ε_{50}, k, γ') in fixed head short pile is higher than free head short pile but is showing the same pattern.

15. The results show that the reliability index connected to Y_{Top} and M_{Max} is very much dependent on the applied lateral load. As the load increases the reliability index is going down.
16. Results indicate that the reliability index connected to Y_{Top} (β_{Ytop}) and M_{Max} (β_{Mmax}) is very sensitive to the random variable 'C'. The influence of other variables on β_{Mmax} is negligible.
17. In descending order, the variables affecting reliability index connected to Y_{Top} in free head pile are, C→ EI→ ε_{50}→ B→ k, and at the end γ'. For fixed head pile: C→ EI→ B→ ε_{50}→ k→ γ'. In fact, variables k and γ' have very negligible effect on reliability index connected to Y_{Top}.
18. In descending order, random variables affecting β_{Mmax} in free and fixed head pile: C→ B→ EI→ ε_{50}→ k→ γ'.
19. In case of reliability index connected to M_{Max}, the free head short (3T) pile structure is safe for all four loads.
20. Reliability index connected to Y_{Top} for free head long pile is lower than free head short pile. While the free head short pile is safe for all four loads, the free head long (10T) pile is failing at top for lateral load 175 kN (fourth load) with reliability index less than 2.
21. Results of reliability index connected to M_{Max} for free head long (10T) pile is slightly lower than free head short (3T) pile.

22. Similar to the free head long (10T) pile, fixed head short (3T) pile has reliability index connected to Y_{Top} lower than 2 (indicate failure) for all 6 random variables at load 375 kN (represents the second straight portion in p-y curve).
23. Fixed head long pile is safer than fixed head short pile (Section 6.3.3) as well as free head long pile (Section 6.2.3) with higher reliability index (β_{Ytop}) especially for the lateral load 375 kN.
24. Compared to fixed head short pile, fixed head long pile has slightly higher values of β_{Mmax}, but still it is lower than 3.7 for all four lateral loads. Hence fixed head pile is more vulnerable to fail by bending moment (M_{Max}) than free head.
25. Overall the reliability index connected to Y_{Top} (β_{Ytop}) and M_{Max} (β_{Mmax}) for fixed head short pile is lower than for free head short pile. This indicates that boundary condition has very profound influence on β_{Mmax}.

7.2 Conclusion on laterally loaded pile group

Following are the characteristics of laterally loaded pile group:

1. The deflection and bending moment obtained in single isolated pile can be obtained in a pile of closely spaced pile group at lower lateral load per pile. It happens because of pile-soil-pile interaction, lateral resistance provided by pile cap.
2. The piles in a group carry unequal lateral loads, depending on their location within the group and the spacing between piles. This unequal distribution of load among piles is caused by shadowing effect.

3. Also higher lateral load (for example 1832 kN) needs to be applied to fixed head long pile group (3D) than hinged head long pile group (3D) (for example 817 kN) to get the same deflection (i.e. 0.005 m).
4. Spacing between the piles in pile group influence the lateral load applied at pile cap to get some specific pile head deflection. Results shows that higher lateral load (for example 898 kN) (Fig. 6.11) needs to be applied to pile cap in a pile group with pile spacing 4D than a pile group with pile spacing 3D (for example 817 kN) to get some specific pile head deflection (for example 0.005 m).
5. As the pile spacing is increases from 3D to 5D, the load distribution in pile A (P_A), pile B (P_B), and pile C (P_C) is getting closure to the lateral load on single pile (P_S).
6. Variation of center-to-center pile spacing from 3D to 5D in a pile group, do not cause any significant change in COV(Y_{Top}) connected to all six random variables.
7. The pattern and values of curve for COV(Y_{Top}) connected to the COV of variables B, C, ε_{50}, γ', k for fixed head long pile group (3D) is very close to COV(Y_{Top}) for fixed head single isolated long pile.
8. In case of M_{Max} for hinged head long pile group, the values for COV(M_{Max}) for pile C (leading row) is going down for all six variables, when we change pile spacing in hinged head pile group from 3D to 5D.
9. COV(M_{Max}) connected to COV of random variables for the pile C (leading row) of hinged head long pile group (3D) is way lower than COV(M_{Max}) for free head single long pile.

10. For COV(M_{Max}) in pile C (leading row) of fixed head pile group, the value remains just about the same for all variables except B when pile spacing in the direction of load changes from 3D to 5D .
11. If we compare the piles in leading, first trailing, and second trailing row of hinged head pile group for COV(M_{Max}), middle row i.e. first trailing row has lower COV(M_{Max}) for all six random variables than the piles of other two rows.
12. Pile in leading, first subsequent and second subsequent are behaving alike for COV(M_{Max}) connected to variables B, C, ε50, EI, γ' in fixed head pile group.
13. The performance of piles in leading, first subsequent, and second subsequent row for all variables do not change when pile spacing is varied from 3D to 5D.
14. The COV(M_{Max}) connected to the COV of all 6 random variables for pile C (leading row) of fixed head long pile group is very high compare to pile C of hinged head pile group.
15. Variation of pile spacing from 3D to 5D in a pile group has no effect on the reliability index connected to Y_{Top} (β_{Ytop}).
16. Whereas in case of reliability index connected to M_{Max} (β_{Mmax}), pile C (leading row) of a pile group becomes more vulnerable to failure from M_{Max} as pile spacing increases from 3D to 5D.
17. Reliability index connected to Y_{Top} (β_{Ytop}) for pile group (3D) is same as β_{Ytop} for single isolated long pile. It is true for both hinged head and fixed head.
18. Reliability index connected to M_{Max} (β_{Mmax}) for pile C (leading row) of hinged head long pile group (3D) is same as (β_{Mmax}) for free head single long pile.
19. Reliability index connected to M_{Max} (β_{Mmax}) for pile C is higher in fixed head pile group than the fixed head single pile.

20. In descending order, variables affecting β_{Ytop} in hinged head long pile group: C→ EI→ ε_{50}→ B→ k→ γ'.
21. In descending order, variables affecting β_{Mmax} in pile C (leading row) of hinged head and fixed head long pile group are: C→ B→ EI→ ε_{50}→ k→ γ'.
22. In descending order, variables affecting β_{Ytop} in fixed head long pile group: C→ B→ EI→ ε_{50}→ k→ γ'.
23. Reliability index (β_{Ytop}) is higher (especially for 4^{th} load) for the fixed head long pile group than the hinged head long pile group.
24. The value for β_{Mmax} is higher for pile C (leading row) of fixed head pile group than pile C (leading row) of hinged head pile group.
25. The hinged head long pile group is failing from Y_{Top} at pile head for the fourth load (representing the second straight portion in p-y curve) with $\beta_{Ytop}<2$.
26. The fixed head long pile group is safe against Y_{Top} with $\beta_{Ytop}>2$ for all 6 random variables under all four lateral loads.
27. The hinged head and fixed head long pile group are safe against M_{Max} with (β_{Mmax})>3.7 for all 6 random variables under all four lateral loads.

7.3 Conclusion on combined load analysis

The analysis of linear and nonlinear system leads to the following conclusion:

1. The pile head deflection produced by nonlinear system is higher than linear system.
2. The corresponding Var(Y_{Top}) for non-linear system is higher than linear system.
3. The corresponding COV(Y_{Top}) for non-linear system is higher than linear system.

4. The variance of limit state serviceability function of nonlinear system is larger than linear system.
5. The reliability index of serviceability of nonlinear system is smaller than linear system.
6. The difference between the reliability index of serviceability of linear and nonlinear system widens as the COV(combined load) increases.

7.4 Recommendations for future research

Reliability analysis provides a systematic account of the uncertainties and a rational procedure for design. Further studies on probabilistic modeling of soil uncertainties will certainly help in improving quality of reliability analysis.

Overly conservative assumptions adopted in some conventional deterministic design methods may be replaced with more objective reliability based design procedure. Therefore study can further be extended for:

1. Laterally loaded pile or pile group surrounded by other kind of soil such as sand.
2. Laterally loaded pile or pile group embedded in non-homogeneous soil.
3. Laterally loaded pile or pile group subjected to more complicated load such as cyclic load, dynamic load.
4. Conducting reliability analysis connected to fatigue limit state on laterally loaded pile or pile group, especially for cyclic and dynamic load.
5. Analyzing the pile made of material other than steel under lateral load.

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APPENDIX A

INPUT AND OUTPUT FILES - COM624P

(Version 2.0)

The earliest version of computer program COM624P was developed by Shih-Tower Wang and Lymon C. Reese in 1989 under the sponsorship of Federal Highway Administration, U. S. DOT. The program is based on widely- used p-y curve method. It is used to analyze the single laterally loaded pile and as an output, program gives pile deflection, rotation, bending moment, and shear by using finite difference method because of the nonlinear response of soil.

Input file for COM624P

Following is the input file for free head laterally loaded single short pile embedded in stiff clay below water table subjected to static lateral load of 132kN.

```
ANALYSIS OF LATERALLY LOADED FREE HEAD SINGLE SHORT PILE
    2    1    0
   70     1     1     0
    2     2     0
     6.150  200000000     0.000      0.000
    1     2
    1     1     1              0
   70      0.00010000      1.00000000
    0.0000     0.5080     0.0005     0.0178
    1     2     0.0000    25.0000 136000.0000
    0.0000    5.90000
   25.0000    5.90000
    0.0000    75.0000     0.0000    0.00700
   25.0000    75.0000     0.0000    0.00700
    5
    0.0300
```

```
0.5000
1.0000
3.0000
4.7100
1
1   132.0000      0.0000      0.0000
```

Here the first line shows the title of the analysis. Line 2 to line 5 indicates the property of pile. Line 6 to line 14 gives the detail of soil (soil thickness: 25m) surrounding the pile and the computation control. Line 15 to line 20 shows the value of depth for which p-y curves are to be calculated for verification. At last, line 21 and 22 specifies the loading condition.

Output file of COM624P

```
ANALYSIS OF LATERALLY LOADED FREE HEAD SINGLE SHORT PILE

UNITS--METR□□□□□□□□□□□□

     ************************************************************
     PILE DEFLECTION, BENDING MOMENT, SHEAR &  SOIL RESISTANCE
     ************************************************************

                    I N P U T   I N F O R M A T I O N
                    *********************************

THE LOADING IS STATIC

PILE GEOMETRY AND PROPERTIES

     PILE LENGTH                        =       6.15  M
     MODULUS OF ELASTICITY OF PILE      =    .200E+06  KN/ M**2
                    1 SECTION(S)

                  X            DIAMETER     MOMENT OF          AREA
                                             INERTIA
                   M                M          M**4             M**2
                  .00
```

```
                                .508       .500E-03       .178E-01
                  6.15
```

```
SOILS INFORMATION

        X-COORDINATE AT THE GROUND SURFACE    =         .00  M

        SLOPE ANGLE AT THE GROUND SURFACE     =         .00 DEG.

        1 LAYER(S) OF SOIL

        LAYER  1
        THE LAYER IS A STIFF CLAY BELOW THE WATER TABLE
        X AT THE TOP OF THE LAYER         =         .00  M
        X AT THE BOTTOM OF THE LAYER      =       25.00  M
        VARIATION OF SOIL MODULUS, k      =    .136E+06  KN/ M**3


        DISTRIBUTION OF EFFECTIVE UNIT WEIGHT WITH DEPTH
                          2 POINTS
                    X, M      WEIGHT,LBS/ M**3
                     .00          .59E+01
                   25.00          .59E+01

        DISTRIBUTION OF STRENGTH PARAMETERS WITH DEPTH
                          2 POINTS
                    X, M        C,LBS/ M**2      PHI,DEGREES      E50
                     .00        .750E+02            .000        .700E-02
                   25.00        .750E+02            .000        .700E-02


    FINITE DIFFERENCE PARAMETERS
        NUMBER OF PILE INCREMENTS                                      =
70
        TOLERANCE ON DETERMINATION OF DEFLECTIONS                      =
.100E-03  M
        MAXIMUM NUMBER OF ITERATIONS ALLOWED FOR PILE ANALYSIS =
70
        MAXIMUM ALLOWABLE DEFLECTION                                   =
.10E+01  M


    INPUT CODES
        OUTPT  =  1
        KCYCL  =  1
        KBC    =  1
        KPYOP  =  1
        INC    =  2
```

ANALYSIS OF LATERALLY LOADED FREE HEAD SINGLE SHORT PILE

UNITS--METR

O U T P U T I N F O R M A T I O N
****

GENERATED P-Y CURVES

THE NUMBER OF CURVE IS = 5

THE NUMBER OF POINTS ON EACH CURVE = 17

DEPTH BELOW GS	DIAM	C	CAVG	GAMMA	E50
M	M	LBS/ M**2	LBS/ M**2	LBS/ M**3	
.03	.508	.8E+02	.8E+02	.6E+01	.700E-02

AS =.24 AC =.21

Y, M	P,LBS/ M
.000	.000
.000	1.719
.001	3.438
.001	5.158
.002	6.877
.002	8.596
.003	10.315
.003	12.035
.003	13.754
.004	15.473
.004	17.192
.005	17.389
.005	15.293
.008	10.414
.012	5.516
.015	.619
.169	.619

DEPTH BELOW GS	DIAM	C	CAVG	GAMMA	E50
M	M	LBS/ M**2	LBS/ M**2	LBS/ M**3	
.50	.508	.8E+02	.8E+02	.6E+01	.700E-02

AS =.46 AC =.29

Y, M	P,LBS/ M
.000	.000
.001	43.900
.002	62.084
.002	71.786
.003	77.690
.004	81.380
.005	83.487
.006	84.366
.006	84.251
.007	83.300
.008	81.632
.009	79.336
.010	76.483
.016	55.555
.023	34.587
.029	13.619
.324	13.619

DEPTH BELOW GS	DIAM	C	CAVG	GAMMA	E50
M	M	LBS/ M**2	LBS/ M**2	LBS/ M**3	
1.00	.508	.8E+02	.8E+02	.6E+01	.700E-02

AS =.55 AC =.30

Y, M	P,LBS/ M
.000	.000
.001	76.221
.002	107.793
.003	125.279
.004	136.412
.005	143.826
.006	148.577
.007	151.271
.008	152.297
.009	151.925
.010	150.355
.011	147.736
.012	144.252
.019	104.385
.027	64.517
.035	24.650
.389	24.650

DEPTH BELOW GS	DIAM	C	CAVG	GAMMA	E50
M	M	LBS/ M**2	LBS/ M**2	LBS/ M**3	

	3.00	.508	.8E+02	.8E+02	.6E+01
.700E-02					

AS =.60	AC =.30	Y, M	P,LBS/ M
		.000	.000
		.001	114.775
		.002	162.317
		.003	189.105
		.004	206.500
		.005	218.381
		.006	226.317
		.007	231.206
		.009	233.625
		.010	233.978
		.011	232.558
		.012	229.590
		.013	225.250
		.021	162.478
		.030	99.613
		.038	36.748
		.427	36.748

DEPTH BELOW GS	DIAM	C	CAVG	GAMMA	E50
M	M	LBS/ M**2	LBS/ M**2	LBS/ M**3	
4.71	.508	.8E+02	.8E+02	.6E+01	.700E-02

AS =.60	AC =.30	Y, M	P,LBS/ M
		.000	.000
		.001	114.775
		.002	162.317
		.003	189.105
		.004	206.500
		.005	218.381
		.006	226.317
		.007	231.206
		.009	233.625
		.010	233.978
		.011	232.558
		.012	229.590
		.013	225.250
		.021	162.478
		.030	99.613
		.038	36.748
		.427	36.748

---------- *** ----------

PILE LOADING CONDITION

LATERAL LOAD AT PILE HEAD = .132E+03 KN
APPLIED MOMENT AT PILE HEAD = .000E+00 M- KN
AXIAL LOAD AT PILE HEAD = .000E+00 KN

X	DEFLECTION	MOMENT	TOTAL STRESS	SHEAR	SOIL RESIST	FLEXURAL RIGIDITY
M	M	M- KN	LBS/ M**2	KN	LBS/ M	KN-M**2
*****	**********	**********	**********	**********	**********	**********
.00	.451E-02	.000E+00	.000E+00	.132E+03	.000E+00	.100E+06
.18	.403E-02	.230E+02	.117E+05	.128E+03	.388E+02	.100E+06
.35	.356E-02	.448E+02	.228E+05	.119E+03	.611E+02	.100E+06
.53	.310E-02	.647E+02	.329E+05	.107E+03	.797E+02	.100E+06
.70	.266E-02	.822E+02	.418E+05	.917E+02	.928E+02	.100E+06
.88	.225E-02	.969E+02	.492E+05	.743E+02	.103E+03	.100E+06
1.05	.186E-02	.108E+03	.550E+05	.554E+02	.109E+03	.100E+06
1.23	.151E-02	.116E+03	.591E+05	.357E+02	.110E+03	.100E+06
1.41	.120E-02	.121E+03	.614E+05	.159E+02	.108E+03	.100E+06
1.58	.923E-03	.122E+03	.619E+05	-.361E+01	.103E+03	.100E+06
1.76	.684E-03	.120E+03	.608E+05	-.216E+02	.883E+02	.100E+06
1.93	.481E-03	.114E+03	.581E+05	-.372E+02	.730E+02	.100E+06
2.11	.314E-03	.107E+03	.542E+05	-.502E+02	.576E+02	.100E+06
2.28	.180E-03	.969E+02	.492E+05	-.609E+02	.416E+02	.100E+06
2.46	.757E-04	.854E+02	.434E+05	-.678E+02	.141E+02	.100E+06
2.64	-.223E-05	.732E+02	.372E+05	-.699E+02	-.104E+02	.100E+06
2.81	-.576E-04	.610E+02	.310E+05	-.679E+02	-.298E+02	.100E+06
2.99	-.940E-04	.495E+02	.251E+05	-.631E+02	-.365E+02	.100E+06
3.16	-.115E-03	.389E+02	.198E+05	-.570E+02	-.390E+02	.100E+06
3.34	-.124E-03	.295E+02	.150E+05	-.504E+02	-.397E+02	.100E+06

```
       3.51  -.124E-03   .212E+02   .108E+05  -.435E+02  -.391E+02
.100E+06
       3.69  -.118E-03   .142E+02   .720E+04  -.367E+02  -.375E+02
.100E+06
       3.87  -.107E-03   .833E+01   .423E+04  -.299E+02  -.352E+02
.100E+06
       4.04  -.933E-04   .364E+01   .185E+04  -.235E+02  -.325E+02
.100E+06
       4.22  -.786E-04   .456E-01   .232E+02  -.175E+02  -.294E+02
.100E+06
       4.39  -.639E-04  -.253E+01   .129E+04  -.120E+02  -.261E+02
.100E+06
       4.57  -.499E-04  -.418E+01   .212E+04  -.692E+01  -.227E+02
.100E+06
       4.74  -.372E-04  -.499E+01   .253E+04  -.244E+01  -.193E+02
.100E+06
       4.92  -.261E-04  -.507E+01   .258E+04   .119E+01  -.133E+02
.100E+06
       5.10  -.164E-04  -.462E+01   .235E+04   .372E+01  -.799E+01
.100E+06
       5.27  -.824E-05  -.381E+01   .193E+04   .523E+01  -.326E+01
.100E+06
       5.45  -.122E-05  -.282E+01   .143E+04   .583E+01   .947E+00
.100E+06
       5.62   .494E-05  -.180E+01   .914E+03   .557E+01   .479E+01
.100E+06
       5.80   .105E-04  -.895E+00   .455E+03   .451E+01   .845E+01
.100E+06
       5.97   .158E-04  -.249E+00   .126E+03   .265E+01   .121E+02
.100E+06
       6.15   .211E-04   .000E+00   .000E+00   .000E+00   .153E+02
.100E+06

         COMPUTED LATERAL FORCE AT PILE HEAD        =   .13200E+00  KN
         COMPUTED MOMENT AT PILE HEAD               =   .00000E+00  M-
KN
         COMPUTED SLOPE AT PILE HEAD                = -.27326E-02

         THE OVERALL MOMENT IMBALANCE               =   .321E-13  M- KN
         THE OVERALL LATERAL FORCE IMBALANCE        =   .268E-11  KN


     OUTPUT SUMMARY

         PILE HEAD DEFLECTION    =   .451E-02  M
         MAXIMUM BENDING MOMENT =   .122E+03  M- KN
         MAXIMUM TOTAL STRESS    =   .619E+05 LBS/ M**2

         NO. OF ITERATIONS         =          4
         MAXIMUM DEFLECTION ERROR  =   .560E-04  M
```

S U M M A R Y T A B L E
****

LATERAL LOAD (KN)	BOUNDARY CONDITION BC2	AXIAL LOAD (KN)	YT (M)	ST (M/ M)	MAX. MOMENT (M- KN)	MAX. STRESS (LBS/ M**2)
.132E+03	.000E+00	.000E+00	.451E-02	-.273E-02	.122E+03	.619E+05

Graphic file of COM624P

To view the p-y curve and curves related to pile deflection, rotation, bending moment, shear and soil reaction, open **C624VIEW** and then specify the graphic file name.

APPENDIX B

INPUT AND OUTPUT FILES – FB-MULTIPIER

(Version 4.0)

The earliest version of program (FB-Pier) was developed by Bridge Software Institute (BSI), University of Florida in 2000. FB-Multipier is the newest development of FB-Pier program. The name has changed to the new capabilities. The program carries out the analysis using p-y curve method and nonlinear finite element method. It can easily analyze single pile, pile group, and multiple piers. To get the further information about the program, visit http://bsi-web.ce.ufl.edu

Input file for FB-Multipier

Following is the input file for free head long pile group (3X3) with c/c spacing of 3D, embedded in stiff clay below water table subjected to 817kN lateral load.

```
PROBLEM
Analysis Time - 6 second(s)
Pile And Cap
Units are KN and Meters
University of Windsor
Analysis of laterally loaded free head long pile group
Shailendra Jadeja
21/06/07


:
PRINT
L=1 M=0 D=1 O=1 S=1 P=1 T=0 F=0 C=0 B=0 J=0 H=0 I=0 R=0 N=0 \
X=0 G=1 A=1 E=1 K=1 Q=0
:
CONTROL
1 U= 1 D= 0 S= 0 K= 0 R= 0 N= 17 Z= 0 E= 0 P= 0 V=1.0 F= 1 \
L= 0 Y= 0 B= 0 G= 0 A= 1
S= 0 T= 0 0 P= 1 F= 0
```

```
I= 60 T= 1 M= 8 X= 0 V= 4.09a
:
SWFACT
1 F= 0 0
:
PILE
NSET= 1 N= 17 S= 0 M= 0 NSEG= 1
C Custom
C T=3 D=2 U=1 : nonlinear
L=20.5 E=2e+008 I=0.00055,0.00055 J=0.0011 G=7.7e+007 \
A=0.0178 D=0.508 S=85.4 K=1
E= 0 H= 0 A= 1 S= 0 G= 0 C= 0
5 5 : NPX, NPY
0.762 1.524 1.524 0.762
0.762 1.524 1.524 0.762
0.55 0.65 0.8
0.55 0.65 0.8
:
MISSING
16 : number of missing piles
1 1
2 1
3 1
4 1
5 1
1 2
5 2
1 3
5 3
1 4
5 4
1 5
2 5
3 5
4 5
5 5
:
SOIL
NSET= 1 L= 1 R= 1 C= 0 W= 0 O= 0 S= 0 B= 0 : Nlayers,kcyc
0 136000 15.71 75 0.007 75 24132 0.3 34.5 25 \
5 1 1 1 0 0 0 0 0 \
E=0,-25 B=0 S=1 A=0
0 136000 15.71 75 0.007 75 24132 0.3 34.5
24132 0.35 2846.7 1 : Soil set 1 tip info
:
SOILSET
:
PILESET
:
CAP
E= 3.04414e+007 U= 0.2 T= 1.65 S= 25
:
LOAD
17 L= 1 F= 817 0 0 0 0 0
:
PADBC
:
```

```
SPANLOAD
:
```

Output file of FB-Multipier

As the output file is very large, only part related to this thesis is shown below:

```
*********************
*   SOIL BEHAVIOR   *
*********************

PY Multipliers will be used (IFLEX = 0)
Axial Efficiency for all piles  (AXEFF)  =  0.000


************************************************
*   LOAD FACTORS FOR SELF WEIGHT AND BUOYANCY   *
************************************************

LOAD CASE     SELF WEIGHT     BUOYANCY
    #            FACTOR        FACTOR
    1             0.00          0.00


***************************
*   GENERAL INFORMATION   *
***************************

Static / Cyclic Load (KCYC)       =     0
   KCYC = 0 -> Static Load
   KCKC > 0 -> Cyclic Load (# Cycles)

Fixity of Pile Cap (KFIX)         =     0
   KFIX = 0 -> Pinned Head
   KFIX = 1 -> Fixed head


Bearing of Cap on Soil            =  NO


****************************
*   GRID DATA INFORMATION   *
****************************

NOTE: X-Grid : Distance between axes along the X-Axis
      Y-Grid : Distance between axes along the Y-Axis

Number of Grid Points in X-Direction (NPX) =     5
Number of Grid Points in X-Direction (NPY) =     5

Grid Spacing in the X Direction : (meters)
```

```
      0.76       1.52       1.52       0.76

 Grid Spacing in the Y Direction : (meters)
      0.76       1.52       1.52       0.76


 ************************
 *   ANALYSIS OPTIONS   *
 ************************

 Type of Stiffness            = Secant Stiffness
 Type of Structure            = Full
 Type of Analysis             = Static Analysis


 ***************************************
 *   INPUT SOIL DATA - GIVEN BY LAYER   *
 ***************************************

 NOTE : The following data is used to define Springs
        for each Soil Layer to determine the Soil
        Behavior during the analysis

 LAYERED P-Y CURVES
 ------------------

 SET   LAYER   MODEL   RK          GAMMA       Cu          E50
Cavg
                      kN/M^3     kN/M^3     kPa                    kPa
   1       1       5  0.1360E+06   15.71       75.00      0.7000E-02
75.00
                      0.1360E+06   15.71       75.00      0.7000E-02
75.00


PILE TIP SOIL PARAMETERS
 ------------------------

 SOIL SET #  1

 Shear Modulus at Tip                 =    24132.000     kPa
 Poisson"s Ratio at Pile Tip          =          0.3500
 Vertical Bearing Failure Load at Tip =    2846.70000000  kN


Section Linear Properties
 -------------------------

 NOTE : These are the elastic properties of the section
        which will be used in the analysis. They are
        provided by the user

 Section Length                      (L) =    20.500000     M
 Youngs Modulus                      (E) =   0.20000000E+09 KPa
 Moment of Inertia         (2 Axis) (I2) =   0.55000000E-03 M^4
 Moment of Inertia         (3 Axis) (I3) =   0.55000000E-03 M^4
 Torsional Moment of Inertia       (J) =   0.11000000E-02 M^4
```

```
 Area of Cross Section                (A) =   0.17800000E-01 M^2
 Weight Density                     (Wden) =    85.400000      KN/M^3

 Circular Section Diameter          (Dia) =   0.50800000     M

 Nonlinear Section/Segment Material Properties
 ---------------------------------------------

 Material Option (MATOPT) =   0
 (Please Refer to the Users Guide for Details)

 - Shape of Section : CIRCULAR

 ***********************************************
  *********************************************
 *   PRINT SOIL GRAPHS FOR EACH PILE NODE   *
 *********************************************

 The following section in the output displays the soil curves
 (P-y,T-z,T-theta) for each pile. The data is printed per pile
 per pile node. Also there is a print for the tip (Q-z) curve

 - Py Plots for Pile #   1
   ----------------------

 Node #   1
 Depth =   0.000
        P              y              P              y              P
y
     KN/m              m           KN/m              m           KN/m
m
    0.0000         0.0000         0.0000         0.0016         0.0000
0.0032
    0.0000         0.0048         0.0000         0.0064         0.0000
0.0080
    0.0000         0.0096         0.0000         0.0112         0.0000
0.0128
    0.0000         0.0144         0.0000         0.0160         0.0000
0.0176
    0.0000         0.0193         0.0000         0.0209         0.0000
0.0225
    0.0000         0.0241         0.0000         0.0257         0.0000
0.0273
    0.0000         0.0289         0.0000         0.0305


 *********************************
 *   PILE SET DATA DESCRIPTION   *
 *********************************

List of Piles Sets and Piles
 ----------------------------

 Pile Set   Piles (that are assigned the Pile Set)
     1       1,  2,  3,  4,  5,  6,  7,  8,  9
```

```
Total Length for Each Pile Set
_____________________________

Pile Set   Length
    1       20.50


************************************
*   INPUT FOR STRUCTURAL ANALYSIS   *
************************************

Number of Joints                    =  81
Number of Different Element Types   =   3
Number of Load Conditions           =   1


*****************************
*   PILE SPATIAL GEOMETRY   *
*****************************

    PILE #         X          Y
      1    0.762       3.81
      2     2.29       3.81
      3     3.81       3.81
      4    0.762       2.29
      5     2.29       2.29
      6     3.81       2.29
      7    0.762      0.762
      8     2.29      0.762
      9     3.81      0.762


************************
************************
*   GENERAL LOAD DATA   *
************************

The table below shows the Applied Loads for every
Load Case. The values in the table represent the
magnitute of the Loads in the specified units

- Applied Load
  NODE  LOAD      X          Y          Z         MXX         MYY
MZZ
                 (KN)       (KN)       (KN)     (KN-M)     (KN-M)     (KN-M)
    17     1    817.00       0.00       0.00       0.00       0.00       0.00


************************
*                      *
*   ANALYSIS RESULTS   *
*                      *
************************


*********************************
*  RESULTS FOR LOAD CASE #      1 *
```

****

NOTE : PY Multipliers are applied Lead to Trail row
based on the actual displacement. If there is
no displacement in a Lateral direction they are
defaulted to 1.0. This can happen in Axial Load
and one direction lateral load cases

PY Multipliers are Applied to A Pile Group

PILE#	X-PYM	Y-PYM
1	0.550E+00	0.800E+00
2	0.650E+00	0.800E+00
3	0.800E+00	0.800E+00
4	0.550E+00	0.650E+00
5	0.650E+00	0.650E+00
6	0.800E+00	0.650E+00
7	0.550E+00	0.550E+00
8	0.650E+00	0.550E+00
9	0.800E+00	0.550E+00

****
* CONVERGENCE REPORT *
****

The Solution Converged in 10 Iterations

Summary of Abs Maximum Out-Of-Balance Forces

FZZ =	0.704E-09	kN
FXX =	0.856E-09	kN
FYY =	0.121E-06	kN
MXX =	0.825E-09	kN-M
MYY =	0.000	kN-M
MZZ =	0.183E-03	kN-M

Summary of Displacements at Pile Heads

Node	X (M)	Y (M)	Z (M)
1	0.479E-02	0.256E-05	0.000E+00
2	0.479E-02	0.326E-05	0.000E+00
3	0.478E-02	0.163E-05	0.000E+00
4	0.480E-02	-0.159E-06	0.000E+00
5	0.479E-02	-0.148E-06	0.000E+00
6	0.478E-02	-0.137E-06	0.000E+00
7	0.479E-02	-0.288E-05	0.000E+00
8	0.479E-02	-0.355E-05	0.000E+00
9	0.478E-02	-0.190E-05	0.000E+00

Summary of Pile Forces for Load CASE 1

2. Pile Shear Force in 2 Direction (kilo-Newtons)

Pile #	Maximum Shear	Minimum Shear
1	0.81707E+02	-0.50679E+02
2	0.89815E+02	-0.56379E+02
3	0.10079E+03	-0.62844E+02
4	0.81767E+02	-0.50713E+02
5	0.89813E+02	-0.56378E+02
6	0.10078E+03	-0.62836E+02
7	0.81708E+02	-0.50679E+02
8	0.89815E+02	-0.56379E+02
9	0.10079E+03	-0.62844E+02

5. Bending Moment About 3 Axis (kN-M)

Pile #	Pile Node	At Depth Below Cap	Maximum Moment	At Depth Below Cap	Minimum Moment
1	1	0.00000E+00	104.7	0.76875E+01	-4.732
2	2	0.00000E+00	115.1	0.64062E+01	-6.341
3	3	0.00000E+00	129.1	0.64062E+01	-8.953
4	4	0.00000E+00	104.8	0.76875E+01	-4.739
5	5	0.00000E+00	115.1	0.64062E+01	-6.341
6	6	0.00000E+00	129.1	0.64062E+01	-8.953
7	7	0.00000E+00	104.7	0.76875E+01	-4.732
8	8	0.00000E+00	115.1	0.64062E+01	-6.341
9	9	0.00000E+00	129.1	0.64062E+01	-8.953

- Analytical Force Results for each Pile

NOTE : The results are presented in the Local Axes (1-2-3) of each Pile. The Orientation of the Local Axes are shown in the Users Manual. The Demand/Capacity Ratio that is Displayed below each Pile Segment refers to the Ratio of the Calculated Force Divided by the Capacity of the Segment

ELEM NO.	NODE NO.	LOAD CASE	FAX (kN)	F22 (kN)	F33 (kN)	M22 (kN-M)	M33 (kN-M)	TORQUE (kN-M)	D/C (Ratio)
! -> Pile Number 4 !									
49	4	1	0.00E+00	0.82E+02	0.46E-02	0.00E+00	0.00E+00	-0.22E-03	
! -> Pile Number 5 !									

```
 ----------------------
   65     5      1      0.00E+00  0.90E+02  0.42E-02  0.00E+00  0.00E+00 -
0.22E-03
 ----------------------
 ! -> Pile Number    6 !
 ----------------------
   81     6      1      0.00E+00  0.10E+03  0.39E-02  0.00E+00  0.00E+00 -
0.22E-03
*************************************************
 *   ANALYTICAL PILE CAP - SHELL STRESS RESULTS   *
 *************************************************


 **********************
 *   DASHPOT FORCES   *
 **********************

 Pile Node#    FXX          FYY          FZZ          MXX          MYY
MZZ
            KN-sec/m     KN-sec/m     KN-sec/m    KN-sec/rad   KN-sec/rad
KN-sec/rad


 *******************************************************
 *     FINAL MAXIMUMS/MINIMUMS FOR ALL LOAD CASES      *
 *                      PIER # 1                       *
 *******************************************************


 Maximum/Minimum Pile Forces
 _____________________________          Value              Load      Comb.
Pile

 Max Shear in 2 Direction         0.1008E+03 KN           1         0
9
 Min Shear in 2 Direction        -0.6284E+02 KN           1         0
9
 Max Shear in 3 Direction         0.9437E-01 KN           1         0
8
 Min Shear in 3 Direction        -0.1024E+00 KN           1         0
2
 Max Moment about 2 Axis          0.1312E+00 KN-M         1         0
2
 Min Moment about 2 Axis         -0.1209E+00 KN-M         1         0
8
 Max Moment about 3 Axis          0.1291E+03 KN-M         1         0
9
 Min Moment about 3 Axis         -0.8953E+01 KN-M         1         0
9
 Max Axial Force                  0.0000E+00 KN           1         0
1
 Min Axial Force                  0.0000E+00 KN           1         0
1
 Max Torsional Force              0.8615E-01 KN-M         1         0
1
 Max Demand/Capacity Ratio        0.3000E+01              1         0
1
```

Maximum/Minimum Soil Forces

Max Axial Soil Force	0.6800E-15	KN	1	05
Min Axial Soil Force	-0.1510E-13	KN	1	08
Max Lateral Force in X dir	0.1245E+03	KN	1	09
Min Lateral Force in X dir	-0.4367E+02	KN	1	09
Max Lateral Force in Y dir	0.1594E+00	KN	1	02
Min Lateral Force in Y dir	-0.1360E+00	KN	1	08
Max Moment About 2 Axis	0.1542E-02	KN-M	1	02
Min Moment About 2 Axis	-0.1661E-02	KN-M	1	08
Max Moment about 3 axis	0.9912E-01	KN-M	1	08
Min Moment about 3 axis	-0.2199E+01	KN-M	1	09
Max Torsional Soil Force	0.3914E-01	KN-M	1	01

Maximum/Minimum Pile Displacements

Max Axial Displacement	0.0000E+00	M	1	01
Min Axial Displacement	0.0000E+00	M	1	01
Max Displacement in X	0.4798E-02	M	1	04
Min Displacement in X	-0.1470E-03	M	1	09
Max Displacement in Y	0.3257E-05	M	1	02
Min Displacement in Y	-0.3553E-05	M	1	08

Graphic file of FB-Multipier

Graphic file of FB-Multipier can be used to see all the results in 3D format. 3D format for displacement is shown below:

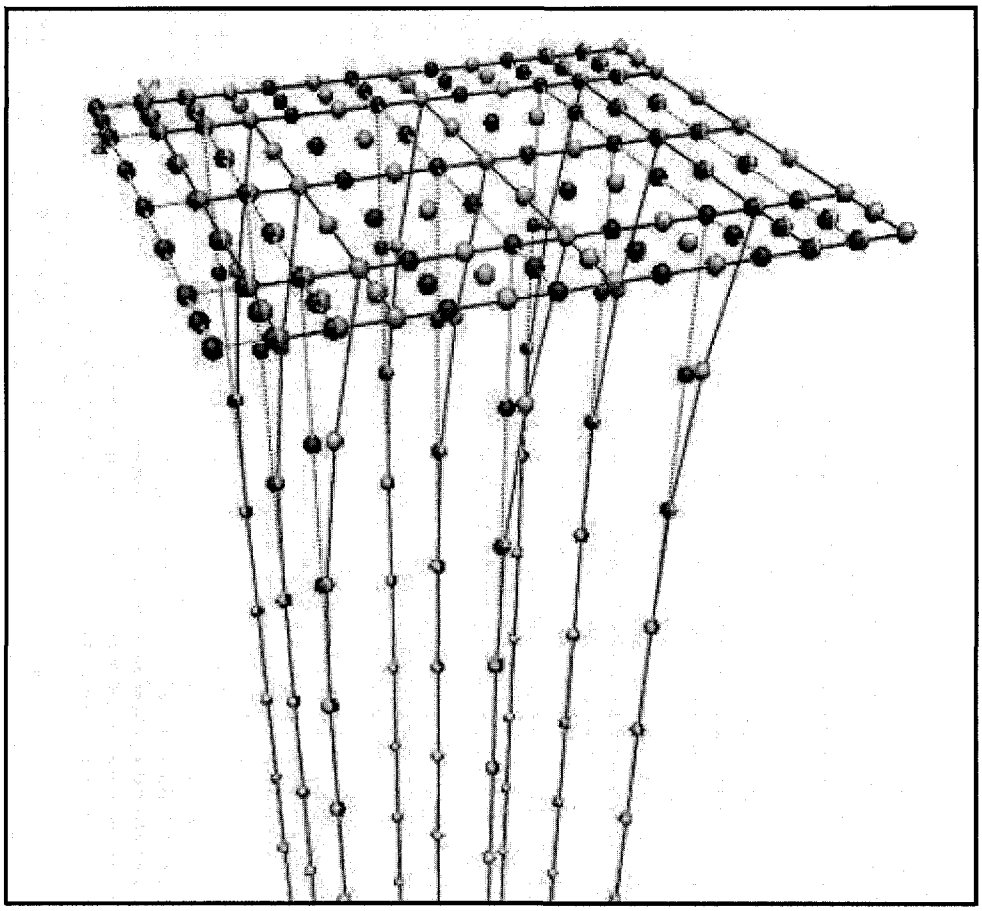

Fig. B.1: 3D picture of the displacement of pile group due to lateral load.

(FB-Multipier)

APPENDIX C

LATERALLY LOADED FREE HEAD SINGLE SHORT PILE (3T)

C.1.1 Probabilistic modeling of laterally loaded free head single short pile (3T) with 'B' as varying random design variable.

Following tables and figures shows the probabilistic modeling of laterally loaded free head single short pile with 'B' as varying random design variable and all the other random design variables are at their mean value.

Table C.1. Values of Y_{Top} for free head single short pile (3T) with varying 'B' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(B) (%)	Var (B) (m)2	$B_{current}$ (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	0.064516	0.254	0.00316	0.00552	0.00774	Failed
45%	0.052258	0.2794	0.00308	0.00518	0.00699	0.0114
40%	0.04129	0.3048	0.00302	0.00493	0.00661	0.00986
35%	0.031613	0.3302	0.00297	0.00475	0.00631	0.00914
30%	0.023226	0.3556	0.00295	0.00469	0.00614	0.00866
25%	0.016129	0.381	0.00293	0.00465	0.00597	0.00831
20%	0.010323	0.4064	0.00292	0.00461	0.00589	0.00811
15%	0.005806	0.4318	0.00291	0.00459	0.00576	0.00797
10%	0.002581	0.4572	0.00291	0.00459	0.00573	0.00781
5%	0.000645	0.4826	0.0029	0.00457	0.00562	0.00773
0%	0	0.508	0.00291	0.00456	0.00561	0.00767
5%	0.000645	0.5334	0.00291	0.00456	0.00561	0.00763
10%	0.002581	0.5588	0.00291	0.00455	0.0056	0.00759
15%	0.005806	0.5842	0.00292	0.00455	0.0056	0.00756
20%	0.010323	0.6096	0.00292	0.00455	0.0056	0.00753
25%	0.016129	0.635	0.00292	0.00455	0.0056	0.00746
30%	0.023226	0.6604	0.00293	0.00455	0.00563	0.00744
35%	0.031613	0.6858	0.00293	0.00455	0.00562	0.00742
40%	0.04129	0.7112	0.00293	0.00455	0.00562	0.0074
45%	0.052258	0.7366	0.00293	0.00455	0.00561	0.00739
50%	0.064516	0.762	0.00294	0.00454	0.00561	0.00737

Table C.2. Values of M_{Max} for free head single short pile (3T) with varying 'B' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(B) (%)	Var (B) (m)2	$B_{current}$ (m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	0.064516	0.254	84.6	126	157	Failed
45%	0.052258	0.2794	84.4	124	151	205
40%	0.04129	0.3048	84.4	122	149	193
35%	0.031613	0.3302	84.5	122	147	188
30%	0.023226	0.3556	84.7	122	146	185
25%	0.016129	0.381	84.9	122	145	183
20%	0.010323	0.4064	85	122	145	182
15%	0.005806	0.4318	85.2	122	145	181
10%	0.002581	0.4572	85.3	122	145	181
5%	0.000645	0.4826	85.3	122	145	180
0%	0	0.508	85.3	122	145	180
5%	0.000645	0.5334	85.3	122	145	180
10%	0.002581	0.5588	85.3	121	145	179
15%	0.005806	0.5842	85.2	121	144	179
20%	0.010323	0.6096	85	121	144	179
25%	0.016129	0.635	84.9	121	144	178
30%	0.023226	0.6604	84.7	121	143	177
35%	0.031613	0.6858	84.5	120	142	176
40%	0.04129	0.7112	84.4	120	142	176
45%	0.052258	0.7366	84.2	120	142	175
50%	0.064516	0.762	84.1	119	141	175

Table C.3(a) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'B' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.00064516	2.5E-11	0.172%	2.50E-11	0.110%
10%	0.00258064	0	0.000%	4.00E-10	0.439%
15%	0.00580644	2.5E-11	0.172%	4.00E-10	0.439%
20%	0.01032256	0	0.000%	9.00E-10	0.658%
25%	0.016129	2.5E-11	0.172%	2.50E-09	1.096%
30%	0.02322576	1E-10	0.344%	4.90E-09	1.535%
35%	0.03161284	4E-10	0.687%	1.00E-08	2.193%
40%	0.04129024	2.025E-09	1.546%	3.61E-08	4.167%
45%	0.05225796	5.625E-09	2.577%	9.92E-08	6.908%
50%	0.064516	1.21E-08	3.780%	2.40E-07	10.746%

Table C.3(b) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'B' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.00064516	2.50E-11	0.089%	2.50E-09	0.652%
10%	0.00258064	4.22E-09	1.159%	1.21E-08	1.434%
15%	0.00580644	6.40E-09	1.426%	4.20E-08	2.673%
20%	0.01032256	2.10E-08	2.585%	8.41E-08	3.781%
25%	0.016129	3.42E-08	3.298%	1.81E-07	5.541%
30%	0.02322576	6.50E-08	4.545%	3.72E-07	7.953%
35%	0.03161284	1.19E-07	6.150%	7.40E-07	11.213%
40%	0.04129024	2.45E-07	8.824%	1.51E-06	16.037%
45%	0.05225796	4.76E-07	12.299%	4.02E-06	26.141%
50%	0.064516	1.13E-06	18.984%	1.36E-05	48.044%

Table C.4(a) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'B' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	0.00064516	0	0.000%	0	0.000%
10%	0.00258064	0	0.000%	0.25	0.410%
15%	0.00580644	0	0.000%	0.25	0.410%
20%	0.01032256	0	0.000%	0.25	0.410%
25%	0.016129	0	0.000%	0.25	0.410%
30%	0.02322576	0	0.000%	0.25	0.410%
35%	0.03161284	0	0.000%	1	0.820%
40%	0.04129024	0	0.000%	1	0.820%
45%	0.05225796	0.01	0.117%	4	1.639%
50%	0.064516	0.0625	0.293%	12.25	2.869%

Table C.4(b) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'B' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	0.00064516	0	0.000%	0	0.000%
10%	0.00258064	0	0.000%	1	0.556%
15%	0.00580644	0.25	0.345%	1	0.556%
20%	0.01032256	0.25	0.345%	2.25	0.833%
25%	0.016129	0.25	0.345%	6.25	1.389%
30%	0.02322576	2.25	1.034%	16	2.222%
35%	0.03161284	6.25	1.724%	36	3.333%
40%	0.04129024	12.25	2.414%	72.25	4.722%
45%	0.05225796	20.25	3.103%	225	8.333%
50%	0.064516	64	5.517%	7656.25	48.611%

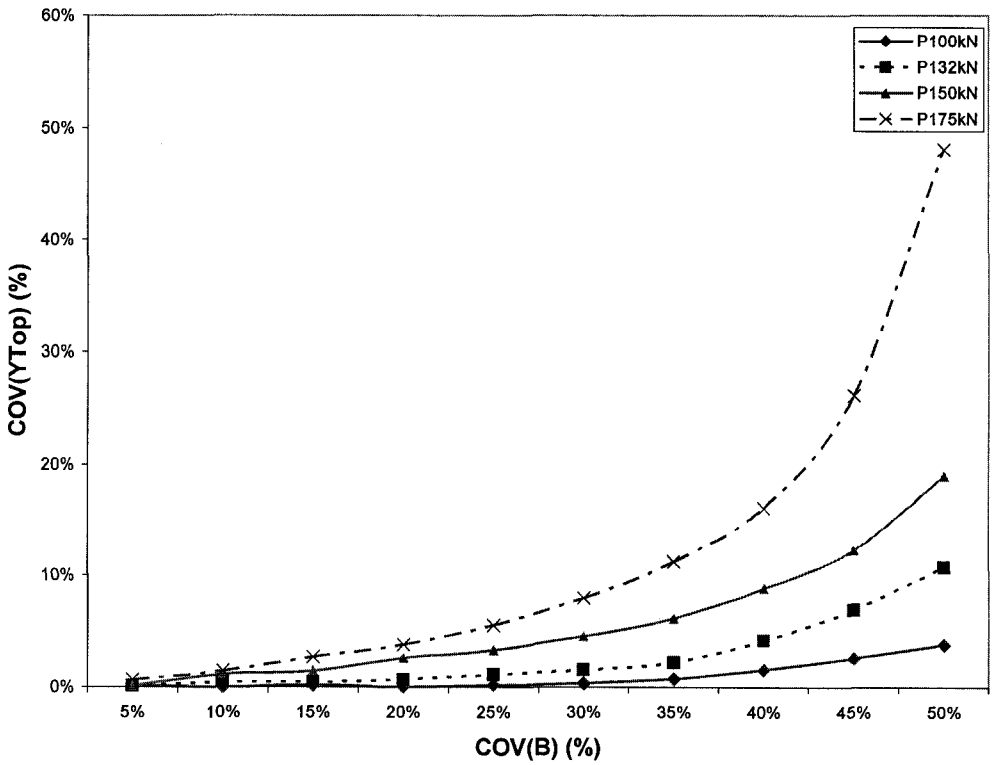

Fig. C.1 COV(Y_{Top}) for varying COV(B) in free head short pile (3T).

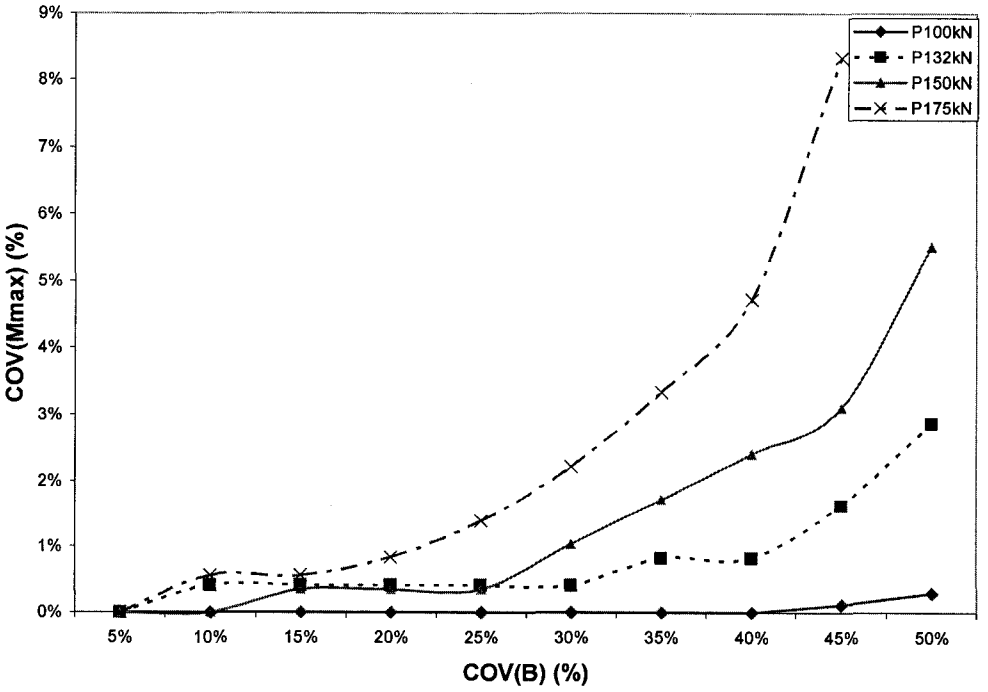

Fig. C.2 COV(M_{Max}) for varying COV(B) in free head short pile (3T).

C.1.2 Probabilistic modeling of laterally loaded free head single short pile (3T) with 'C' as varying random design variable

Following tables and figures shows the probabilistic modeling of laterally loaded free head single short pile with 'C' as varying random design variable and all the other random design variables are at their mean value.

Table C.5. Values of Y_{Top} for free head single short pile (3T) with varying 'C' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(C) (%)	Var (c) $(kPa)^2$	Ccurrent (kPa)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	1406.25	37.5	0.00611	0.0108	0.0151	Failed
45%	1139.0625	41.25	0.00547	0.00944	0.0127	0.0203
40%	900	45	0.00492	0.00844	0.0111	0.0165
35%	689.0625	48.75	0.00446	0.00759	0.00987	0.0142
30%	506.25	52.5	0.0041	0.00688	0.00896	0.0126
25%	351.5625	56.25	0.00384	0.00635	0.00815	0.0114
20%	225	60	0.00362	0.00584	0.00747	0.0103
15%	126.5625	63.75	0.00341	0.0054	0.00695	0.00954
10%	56.25	67.5	0.00322	0.00504	0.00644	0.0088
5%	14.0625	71.25	0.00305	0.00479	0.00606	0.00822
0%	0	75	0.00291	0.00456	0.00561	0.00767
5%	14.0625	78.75	0.00277	0.00434	0.00536	0.00723
10%	56.25	82.5	0.00266	0.00414	0.00514	0.0068
15%	126.5625	86.25	0.00255	0.00396	0.0049	0.00641
20%	225	90	0.00247	0.0038	0.0047	0.00609
25%	351.5625	93.75	0.00239	0.00365	0.0045	0.00587
30%	506.25	97.5	0.00232	0.00351	0.00433	0.00563
35%	689.0625	101.25	0.00225	0.00335	0.00417	0.00542
40%	900	105	0.00212	0.00324	0.00403	0.00522
45%	1139.0625	108.75	0.00209	0.00315	0.00385	0.00503
50%	1406.25	112.5	0.00207	0.00306	0.00373	0.00487

Table C.6. Values of M_{Max} for free head single short pile (3T) with varying 'C' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(C) (%)	Var (c) $(kPa)^2$	Ccurrent (kPa)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	1406.25	37.5	112	167	207	Failed
45%	1139.0625	41.25	107	159	195	259
40%	900	45	103	153	185	240
35%	689.0625	48.75	99.7	147	177	227
30%	506.25	52.5	96.5	142	171	217
25%	351.5625	56.25	95.3	138	165	209
20%	225	60	92.5	133	160	202
15%	126.5625	63.75	90.5	130	156	195
10%	56.25	67.5	88.7	127	151	190
5%	14.0625	71.25	87	125	148	185
0%	0	75	85.3	122	145	180
5%	14.0625	78.75	83.9	120	142	176
10%	56.25	82.5	82.5	117	139	172
15%	126.5625	86.25	81.3	115	137	168
20%	225	90	80.2	114	134	166
25%	351.5625	93.75	79	112	132	163
30%	506.25	97.5	78	110	130	160
35%	689.0625	101.25	77	108	128	158
40%	900	105	74.8	106	126	155
45%	1139.0625	108.75	74.2	105	124	153
50%	1406.25	112.5	73.6	104	122	151

Table C.7(a) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'C' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(C) (%)	Var (c) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	14.0625	1.96E-08	4.811%	5.06E-08	4.934%
10%	56.25	7.84E-08	9.622%	2.03E-07	9.868%
15%	126.5625	1.849E-07	14.777%	5.18E-07	15.789%
20%	225	3.30625E-07	19.759%	1.04E-06	22.368%
25%	351.5625	5.25625E-07	24.914%	1.82E-06	29.605%
30%	506.25	7.921E-07	30.584%	2.84E-06	36.952%
35%	689.0625	1.22103E-06	37.973%	4.49E-06	46.491%
40%	900	0.00000196	48.110%	6.76E-06	57.018%
45%	1139.0625	2.8561E-06	58.076%	9.89E-06	68.969%
50%	1406.25	4.0804E-06	69.416%	1.50E-05	84.868%

Table C.7(b) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'C' and lateral load 150 kN and 175kN.

		P=150 kN		P=175 kN	
COV(C) (%)	Var (c) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	14.0625	1.23E-07	6.239%	2.45E-07	6.454%
10%	56.25	4.23E-07	11.586%	1.00E-06	13.038%
15%	126.5625	1.05E-06	18.271%	2.45E-06	20.404%
20%	225	1.92E-06	24.688%	4.43E-06	27.445%
25%	351.5625	3.33E-06	32.531%	7.65E-06	36.050%
30%	506.25	5.36E-06	41.266%	1.21E-05	45.437%
35%	689.0625	8.12E-06	50.802%	1.93E-05	57.236%
40%	900	1.25E-05	63.012%	3.18E-05	73.533%
45%	1139.0625	1.96E-05	78.877%	5.83E-05	99.544%
50%	1406.25	3.23E-05	101.337%	5.93E-06	

Table C.8(a) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'C' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(C) (%)	Var (c) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	14.0625	2.4025	1.817%	6.25	2.049%
10%	56.25	9.61	3.634%	25	4.098%
15%	126.5625	21.16	5.393%	56.25	6.148%
20%	225	37.8225	7.210%	90.25	7.787%
25%	351.5625	66.4225	9.555%	169	10.656%
30%	506.25	85.5625	10.844%	256	13.115%
35%	689.0625	128.8225	13.306%	380.25	15.984%
40%	900	198.81	16.530%	552.25	19.262%
45%	1139.0625	268.96	19.226%	729	22.131%
50%	1406.25	368.64	22.509%	992.25	25.820%

Table C.8(b) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'C' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(C) (%)	Var (c) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	14.0625	9	2.069%	20.25	2.500%
10%	56.25	36	4.138%	81	5.000%
15%	126.5625	90.25	6.552%	182.25	7.500%
20%	225	169	8.966%	324	10.000%
25%	351.5625	272.25	11.379%	529	12.778%
30%	506.25	420.25	14.138%	812.25	15.833%
35%	689.0625	600.25	16.897%	1190.25	19.167%
40%	900	870.25	20.345%	1806.25	23.611%
45%	1139.0625	1260.25	24.483%	2809	29.444%
50%	1406.25	1806.25	29.310%	5700.25	41.944%

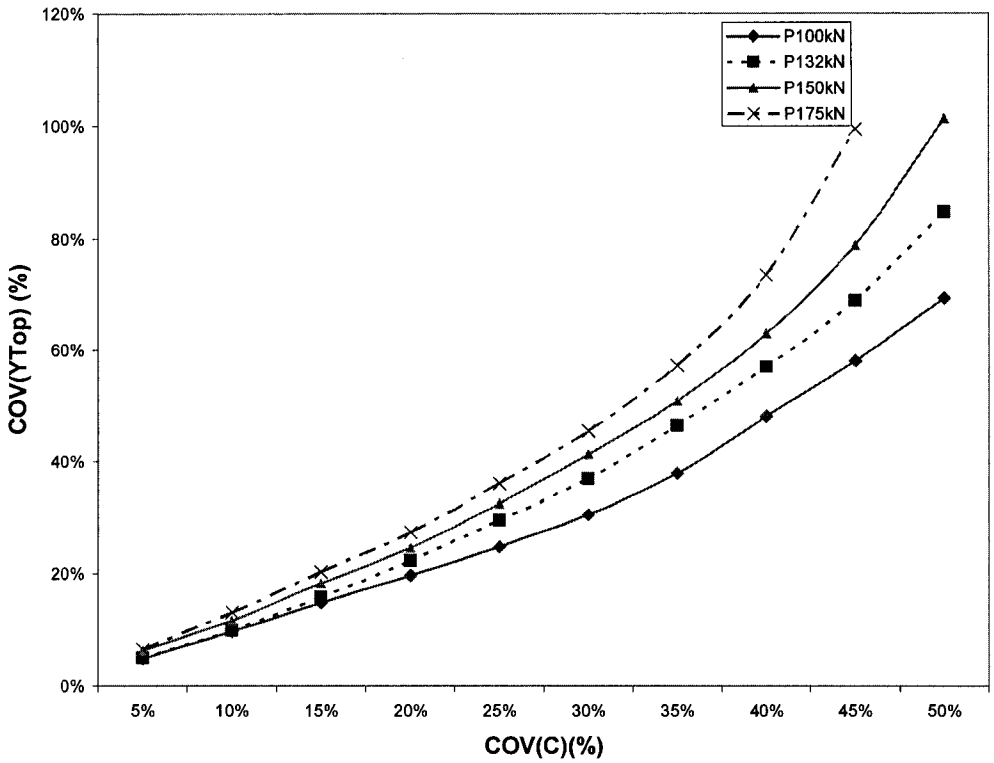

Fig. C.3 COV(Y_{Top}) for varying COV(C) in free head short pile (3T).

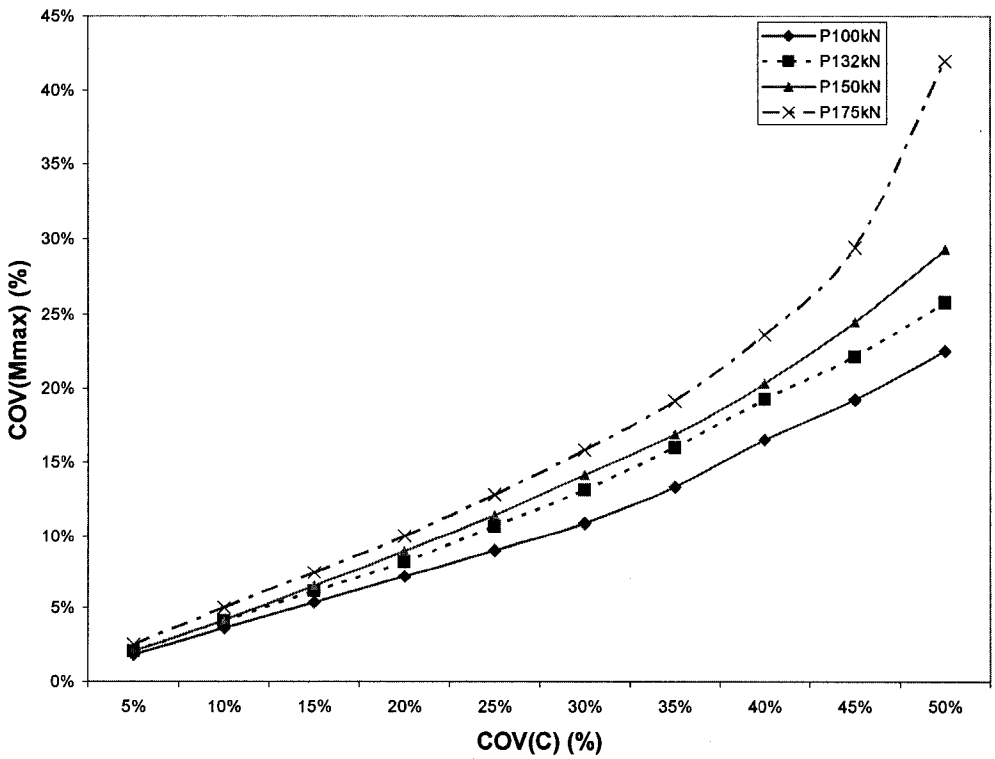

Fig. C.4 COV(M_{Max}) for varying COV(C) in free head short pile (3T).

C.1.3 Probabilistic modeling of laterally loaded free head single short pile (3T) with 'ε_{50}' as varying random design variable

Following tables and figures shows the probabilistic modeling of laterally loaded free head single short pile with 'ε_{50}' as varying random design variable and all the other random design variables are at their mean value.

Table C.9. Values of Y_{Top} for free head single short pile (3T) with varying 'ε_{50}' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	0.00001225	0.0035	0.00232	0.00373	0.00482	0.00657
45%	9.9225E-06	0.00385	0.00238	0.00381	0.00477	0.00666
40%	0.00000784	0.0042	0.00243	0.00389	0.00486	0.00676
35%	6.0025E-06	0.00455	0.00249	0.00398	0.00496	0.00687
30%	0.00000441	0.0049	0.00255	0.00406	0.00505	0.00698
25%	3.0625E-06	0.00525	0.00261	0.00415	0.00515	0.0071
20%	0.00000196	0.0056	0.00267	0.00423	0.00524	0.00721
15%	1.1025E-06	0.00595	0.00273	0.00432	0.00534	0.00733
10%	0.00000049	0.0063	0.00279	0.0044	0.00543	0.00744
5%	1.225E-07	0.00665	0.00285	0.00448	0.00552	0.00756
0%	0	0.007	0.00291	0.00456	0.005651	0.00767
5%	1.225E-07	0.00735	0.00296	0.00464	0.0057	0.00778
10%	0.00000049	0.0077	0.00302	0.00472	0.00579	0.00789
15%	1.1025E-06	0.00805	0.00307	0.0048	0.00595	0.008
20%	0.00000196	0.0084	0.00313	0.00488	0.00604	0.00811
25%	3.0625E-06	0.00875	0.00318	0.00495	0.00613	0.00822
30%	0.00000441	0.0091	0.00324	0.00503	0.00621	0.00833
35%	6.0025E-06	0.00945	0.00329	0.0051	0.0063	0.00843
40%	0.00000784	0.0098	0.00334	0.00518	0.00638	0.00854
45%	9.9225E-06	0.01015	0.00339	0.00525	0.00647	0.00864
50%	0.00001225	0.0105	0.00344	0.00529	0.00661	0.00874

Table C.10. Values of M_{Max} for free head single short pile (3T) with varying 'ε_{50}' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	0.00001225	0.0035	79.6	118	142	180
45%	9.9225E-06	0.00385	80.3	118	142	180
40%	0.00000784	0.0042	80.9	118	142	179
35%	6.0025E-06	0.00455	81.6	119	142	179
30%	0.00000441	0.0049	82.3	119	143	179
25%	3.0625E-06	0.00525	82.8	120	143	179
20%	0.00000196	0.0056	83.4	120	143	179
15%	1.1025E-06	0.00595	83.9	121	144	179
10%	0.00000049	0.0063	84.4	121	144	180
5%	1.225E-07	0.00665	84.8	121	144	180
0%	0	0.007	85.3	122	145	180
5%	1.225E-07	0.00735	85.8	122	145	180
10%	0.00000049	0.0077	86.3	123	146	181
15%	1.1025E-06	0.00805	86.8	123	146	181
20%	0.00000196	0.0084	87.2	124	146	181
25%	3.0625E-06	0.00875	87.6	124	146	182
30%	0.00000441	0.0091	88	125	147	182
35%	6.0025E-06	0.00945	88.4	125	147	182
40%	0.00000784	0.0098	88.8	125	148	183
45%	9.9225E-06	0.01015	89.2	126	148	183
50%	0.00001225	0.0105	89.5	127	149	183

Table C.11(a) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'ε_{50}' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.225E-07	3.025E-09	1.890%	6.40E-09	1.754%
10%	0.00000049	1.3225E-08	3.952%	2.56E-08	3.509%
15%	1.1025E-06	2.89E-08	5.842%	5.76E-08	5.263%
20%	0.00000196	5.29E-08	7.904%	1.06E-07	7.127%
25%	3.0625E-06	8.1225E-08	9.794%	1.60E-07	8.772%
30%	0.00000441	1.19025E-07	11.856%	2.35E-07	10.636%
35%	6.0025E-06	0.00000016	13.746%	3.14E-07	12.281%
40%	0.00000784	2.07025E-07	15.636%	4.16E-07	14.145%
45%	9.9225E-06	2.55025E-07	17.354%	5.18E-07	15.789%
50%	0.00001225	3.136E-07	19.244%	6.08E-07	17.105%

Table C.11(b) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'ε_{50}' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.225E-07	8.10E-09	1.604%	1.21E-08	1.434%
10%	0.00000049	3.24E-08	3.209%	5.06E-08	2.934%
15%	1.1025E-06	9.30E-08	5.437%	1.12E-07	4.368%
20%	0.00000196	1.60E-07	7.130%	2.03E-07	5.867%
25%	3.0625E-06	2.40E-07	8.734%	3.14E-07	7.301%
30%	0.00000441	3.36E-07	10.339%	4.56E-07	8.801%
35%	6.0025E-06	4.49E-07	11.943%	6.08E-07	10.169%
40%	0.00000784	5.78E-07	13.547%	7.92E-07	11.604%
45%	9.9225E-06	7.23E-07	15.152%	9.80E-07	12.907%
50%	0.00001225	8.01E-07	15.954%	1.18E-06	14.146%

Table C.12(a) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'ε_{50}' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	1.225E-07	0.25	0.586%	0.25	0.410%
10%	4.900E-07	0.9025	1.114%	1	0.820%
15%	1.103E-06	2.1025	1.700%	1	0.820%
20%	1.960E-06	3.61	2.227%	4	1.639%
25%	3.063E-06	5.76	2.814%	4	1.639%
30%	4.410E-06	8.1225	3.341%	9	2.459%
35%	6.003E-06	11.56	3.986%	9	2.459%
40%	7.840E-06	15.6025	4.631%	12.25	2.869%
45%	9.923E-06	19.8025	5.217%	16	3.279%
50%	1.225E-05	24.5025	5.803%	20.25	3.689%

Table C.12(b) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'ε_{50}' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	1.225E-07	0.25	0.345%	0	0.000%
10%	4.900E-07	1	0.690%	0.25	0.278%
15%	1.103E-06	1	0.690%	1	0.556%
20%	1.960E-06	2.25	1.034%	1	0.556%
25%	3.063E-06	2.25	1.034%	2.25	0.833%
30%	4.410E-06	4	1.379%	2.25	0.833%
35%	6.003E-06	6.25	1.724%	2.25	0.833%
40%	7.840E-06	9	2.069%	4	1.111%
45%	9.923E-06	9	2.069%	2.25	0.833%
50%	1.225E-05	12.25	2.414%	2.25	0.833%

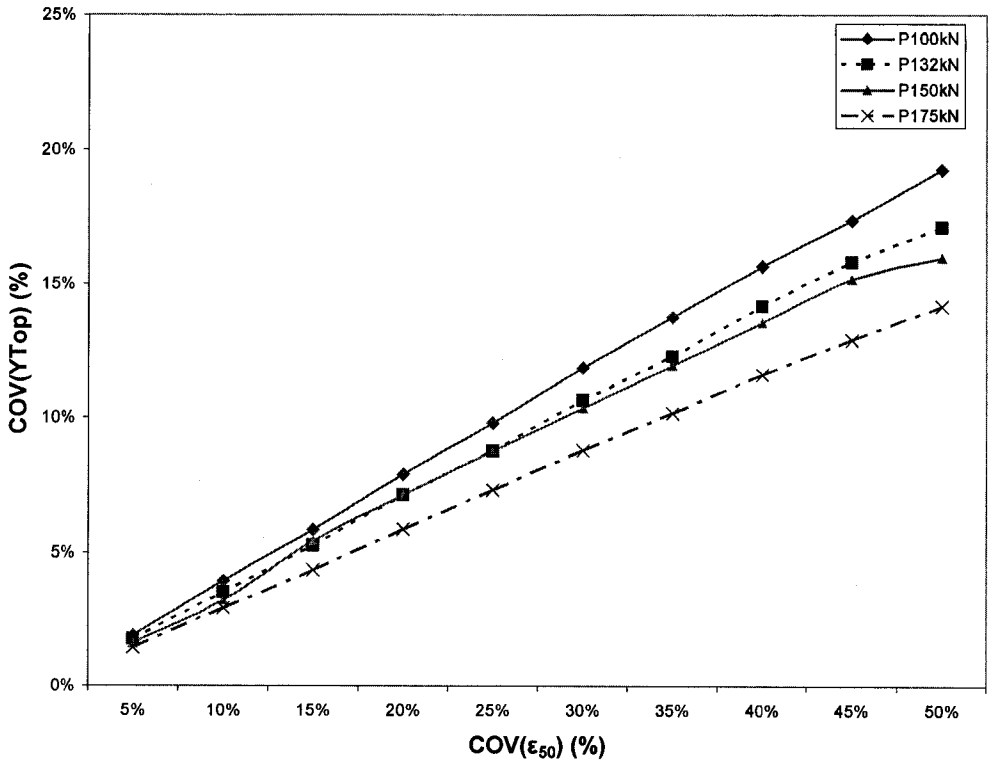

Fig. C.5 COV(Y_{Top}) for varying COV(ε_{50}) in free head short pile (3T).

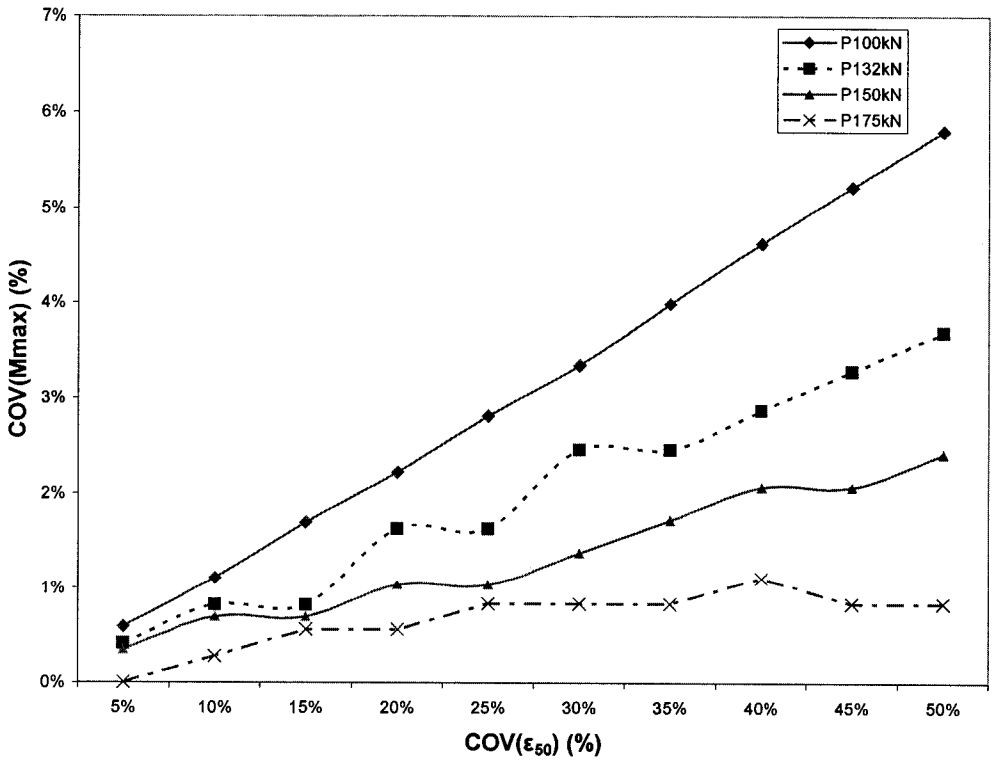

Fig. C.6 COV(M_{Max}) for varying COV(ε_{50}) in free head short pile (3T).

C.1.4 Probabilistic modeling of laterally loaded free head single short pile (3T) with 'EI' as varying random design variable

Following tables and figures shows the probabilistic modeling of laterally loaded free head single short pile with 'EI' as varying random design variable and all the other random design variables are at their mean value.

Table C.13 Values of Y_{Top} for free head single short pile (3T) with varying 'EI' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(kN.m^2)$	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	3.03E+09	55000	0.00406	0.00654	0.00848	0.0119
45%	2.45E+09	60500	0.00394	0.00634	0.0082	0.0114
40%	1.94E+09	66000	0.00384	0.0061	0.00795	0.011
35%	1.48E+09	71500	0.00375	0.00595	0.00773	0.0107
30%	1.09E+09	77000	0.00367	0.00582	0.00753	0.0104
25%	7.56E+08	82500	0.00359	0.0057	0.00735	0.0101
20%	4.84E+08	88000	0.00353	0.00558	0.00713	0.00982
15%	2.72E+08	93500	0.00304	0.00479	0.00598	0.00811
10%	1.21E+08	99000	0.00299	0.00471	0.00579	0.00795
5%	3.03E+07	104500	0.00295	0.00463	0.0057	0.00781
0%	0.00E+00	110000	0.00291	0.00456	0.00561	0.00767
5%	3.03E+07	115500	0.00287	0.0045	0.00553	0.00754
10%	1.21E+08	121000	0.00283	0.00443	0.00545	0.00742
15%	2.72E+08	126500	0.00279	0.00437	0.00538	0.00731
20%	4.84E+08	132000	0.00276	0.00432	0.00531	0.00721
25%	7.56E+08	137500	0.00247	0.00383	0.00472	0.00626
30%	1.09E+09	143000	0.00244	0.00379	0.00466	0.00618
35%	1.48E+09	148500	0.00242	0.00375	0.00461	0.0061
40%	1.94E+09	154000	0.00239	0.00371	0.00456	0.00603
45%	2.45E+09	159500	0.00237	0.00367	0.00452	0.00596
50%	3.03E+09	165000	0.00235	0.00364	0.00447	0.0059

Table C.14. Values of M_{Max} for free head single short pile (3T) with varying 'EI' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(kN.m^2)$	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	3.03E+09	55000	80.4	117	142	180
45%	2.45E+09	60500	80.8	117	142	180
40%	1.94E+09	66000	81.1	118	142	180
35%	1.48E+09	71500	81.5	118	142	180
30%	1.09E+09	77000	81.8	119	142	180
25%	7.56E+08	82500	82.1	119	142	180
20%	4.84E+08	88000	82.3	119	142	180
15%	2.72E+08	93500	84.5	121	144	180
10%	1.21E+08	99000	84.8	121	144	180
5%	3.03E+07	104500	85.1	122	145	180
0%	0.00E+00	110000	85.3	122	145	180
5%	3.03E+07	115500	85.6	122	145	180
10%	1.21E+08	121000	85.9	122	145	180
15%	2.72E+08	126500	86.1	122	146	180
20%	4.84E+08	132000	86.3	123	146	181
25%	7.56E+08	137500	88.5	125	148	182
30%	1.09E+09	143000	88.7	125	149	182
35%	1.48E+09	148500	88.9	126	149	183
40%	1.94E+09	154000	89.1	126	149	183
45%	2.45E+09	159500	89.3	126	149	183
50%	3.03E+09	165000	89.5	126	150	183

Table C.15(a) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'EI' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	1.6E-09	1.375%	4.22E-09	1.425%
10%	1.21E+08	6.4E-09	2.749%	1.96E-08	3.070%
15%	2.72E+08	1.5625E-08	4.296%	4.41E-08	4.605%
20%	4.84E+08	1.48225E-07	13.230%	3.97E-07	13.816%
25%	7.56E+08	3.136E-07	19.244%	8.74E-07	20.504%
30%	1.09E+09	3.78225E-07	21.134%	1.03E-06	22.259%
35%	1.48E+09	4.42225E-07	22.852%	1.21E-06	24.123%
40%	1.94E+09	5.25625E-07	24.914%	1.43E-06	26.206%
45%	2.45E+09	6.16225E-07	26.976%	1.78E-06	29.276%
50%	3.03E+09	7.31025E-07	29.381%	2.10E-06	31.798%

Table C.15(b) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'EI' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	7.23E-09	1.515%	1.82E-08	1.760%
10%	1.21E+08	2.89E-08	3.030%	7.02E-08	3.455%
15%	2.72E+08	9.00E-08	5.348%	1.60E-07	5.215%
20%	4.84E+08	8.28E-07	16.221%	1.70E-06	17.014%
25%	7.56E+08	1.73E-06	23.440%	3.69E-06	25.033%
30%	1.09E+09	2.06E-06	25.579%	4.45E-06	27.510%
35%	1.48E+09	2.43E-06	27.807%	5.29E-06	29.987%
40%	1.94E+09	2.87E-06	30.214%	6.18E-06	32.399%
45%	2.45E+09	3.39E-06	32.799%	7.40E-06	35.463%
50%	3.03E+09	4.02E-06	35.740%	9.00E-06	39.113%

Table C.16(a) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'EI' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	0.0625	0.293%	0	0.000%
10%	1.21E+08	0.3025	0.645%	0.25	0.410%
15%	2.72E+08	0.64	0.938%	0.25	0.410%
20%	4.84E+08	4	2.345%	4	1.639%
25%	7.56E+08	10.24	3.751%	9	2.459%
30%	1.09E+09	11.9025	4.045%	9	2.459%
35%	1.48E+09	13.69	4.338%	16	3.279%
40%	1.94E+09	16	4.689%	16	3.279%
45%	2.45E+09	18.0625	4.982%	20.25	3.689%
50%	3.03E+09	20.7025	5.334%	20.25	3.689%

Table C.16(b) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'EI' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	0	0.000%	0	0.000%
10%	1.21E+08	0.25	0.345%	0	0.000%
15%	2.72E+08	1	0.690%	0	0.000%
20%	4.84E+08	4	1.379%	0.25	0.278%
25%	7.56E+08	9	2.069%	1	0.556%
30%	1.09E+09	12.25	2.414%	1	0.556%
35%	1.48E+09	12.25	2.414%	2.25	0.833%
40%	1.94E+09	12.25	2.414%	2.25	0.833%
45%	2.45E+09	12.25	2.414%	2.25	0.833%
50%	3.03E+09	16	2.759%	2.25	0.833%

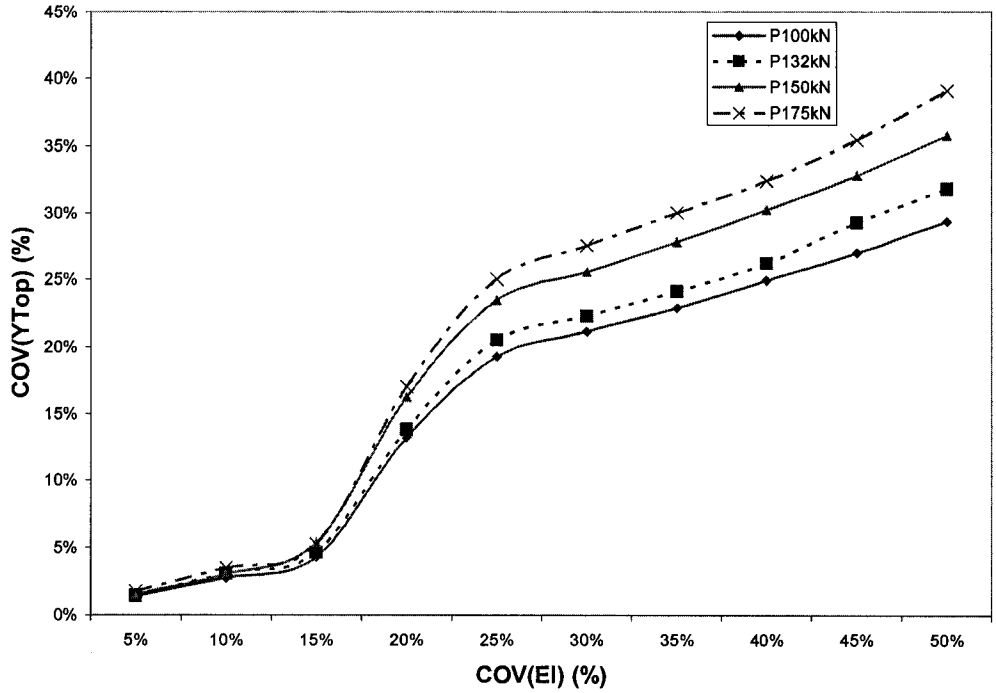

Fig. C.7 COV(Y_{Top}) for varying COV(EI) in free head short pile (3T).

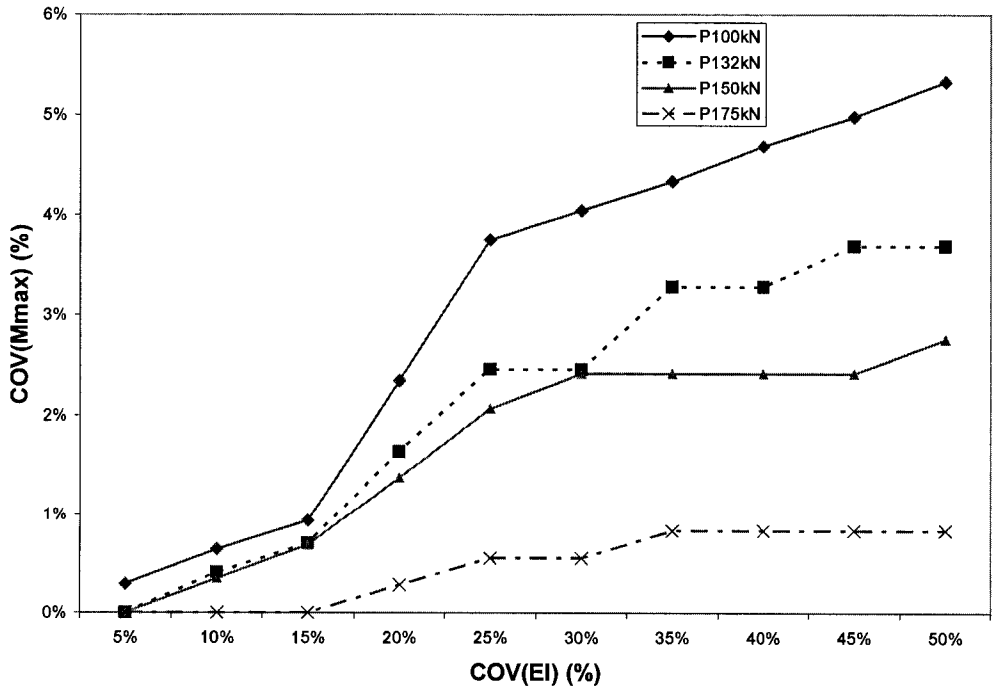

Fig. C.8 COV(M_{Max}) for varying COV(EI) in free head short pile (3T).

C.1.5 Probabilistic modeling of laterally loaded free head single short pile (3T) with 'k' as varying random design variable

Following tables and figures shows the probabilistic modeling of laterally loaded free head single short pile with 'k' as varying random design variable and all the other random design variables are at their mean value.

Table C.17 Values of Y_{Top} for free head single short pile (3T) with varying 'k' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current(m)
50%	4.62E+09	68000	0.00312	0.00472	0.00591	0.00774
45%	3.75E+09	74800	0.00306	0.00467	0.00586	0.00766
40%	2.96E+09	81600	0.00304	0.00468	0.00583	0.00759
35%	2.27E+09	88400	0.003	0.00466	0.0058	0.0077
30%	1.66E+09	95200	0.00298	0.00464	0.00578	0.00768
25%	1.16E+09	102000	0.00295	0.00462	0.00575	0.00766
20%	7.40E+08	108800	0.00294	0.00461	0.00571	0.0077
15%	4.16E+08	115600	0.00293	0.00459	0.00569	0.0077
10%	1.85E+08	122400	0.00292	0.00458	0.00566	0.00769
5%	4.62E+07	129200	0.00291	0.00457	0.00564	0.00768
0%	0.00E+00	136000	0.00291	0.00456	0.00561	0.00767
5%	4.62E+07	142800	0.0029	0.00455	0.00559	0.00766
10%	1.85E+08	149600	0.0029	0.00455	0.00565	0.00766
15%	4.16E+08	156400	0.00289	0.00452	0.00564	0.00765
20%	7.40E+08	163200	0.00289	0.00451	0.00563	0.00764
25%	1.16E+09	170000	0.00288	0.0045	0.00569	0.0077
30%	1.66E+09	176800	0.00288	0.00448	0.00568	0.0077
35%	2.27E+09	183600	0.00288	0.00447	0.00568	0.00769
40%	2.96E+09	190400	0.00287	0.00446	0.00567	0.00769
45%	3.75E+09	197200	0.00287	0.00445	0.00567	0.00769
50%	4.62E+09	204000	0.00287	0.00444	0.00566	0.00768

Table C.18. Values of M_{Max} for free head single short pile (3T) with varying 'k' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	4.62E+09	68000	84.4	122	146	181
45%	3.75E+09	74800	84.8	122	146	180
40%	2.96E+09	81600	85.4	122	146	180
35%	2.27E+09	88400	85.5	122	145	180
30%	1.66E+09	95200	85.6	122	145	180
25%	1.16E+09	102000	85.5	122	145	180
20%	7.40E+08	108800	85.4	122	145	180
15%	4.16E+08	115600	85.4	122	145	180
10%	1.85E+08	122400	85.4	122	145	180
5%	4.62E+07	129200	85.4	122	145	180
0%	0.00E+00	136000	85.3	122	145	180
5%	4.62E+07	142800	85.3	122	145	180
10%	1.85E+08	149600	85.3	122	144	180
15%	4.16E+08	156400	85.3	122	144	180
20%	7.40E+08	163200	85.3	122	144	180
25%	1.16E+09	170000	85.2	122	144	180
30%	1.66E+09	176800	85.2	122	144	180
35%	2.27E+09	183600	85.2	122	144	180
40%	2.96E+09	190400	85.2	122	144	180
45%	3.75E+09	197200	85.2	122	144	180
50%	4.62E+09	204000	85.1	122	144	180

Table C.19(a) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'k' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.5E-11	0.172%	1.00E-10	0.219%
10%	1.85E+08	1E-10	0.344%	2.25E-10	0.329%
15%	4.16E+08	4E-10	0.687%	1.23E-09	0.768%
20%	7.40E+08	6.25E-10	0.859%	2.50E-09	1.096%
25%	1.16E+09	1.225E-09	1.203%	3.60E-09	1.316%
30%	1.66E+09	2.5E-09	1.718%	6.40E-09	1.754%
35%	2.27E+09	3.6E-09	2.062%	9.03E-09	2.083%
40%	2.96E+09	7.225E-09	2.921%	1.21E-08	2.412%
45%	3.75E+09	9.025E-09	3.265%	1.21E-08	2.412%
50%	4.62E+09	1.5625E-08	4.296%	1.96E-08	3.070%

Table C.19(b) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'k' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	6.25E-10	0.446%	1.00E-10	0.130%
10%	1.85E+08	2.50E-11	0.089%	2.25E-10	0.196%
15%	4.16E+08	6.25E-10	0.446%	6.25E-10	0.326%
20%	7.40E+08	1.60E-09	0.713%	9.00E-10	0.391%
25%	1.16E+09	9.00E-10	0.535%	4.00E-10	0.261%
30%	1.66E+09	2.50E-09	0.891%	1.00E-10	0.130%
35%	2.27E+09	3.60E-09	1.070%	2.50E-11	0.065%
40%	2.96E+09	6.40E-09	1.426%	2.50E-09	0.652%
45%	3.75E+09	9.03E-09	1.693%	2.25E-10	0.196%
50%	4.62E+09	1.56E-08	2.228%	9.00E-10	0.391%

Table C.20(a) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'k' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0.0025	0.059%	0	0.000%
10%	1.85E+08	0.0025	0.059%	0	0.000%
15%	4.16E+08	0.0025	0.059%	0	0.000%
20%	7.40E+08	0.0025	0.059%	0	0.000%
25%	1.16E+09	0.0225	0.176%	0	0.000%
30%	1.66E+09	0.04	0.234%	0	0.000%
35%	2.27E+09	0.0225	0.176%	0	0.000%
40%	2.96E+09	0.01	0.117%	0	0.000%
45%	3.75E+09	0.04	0.234%	0	0.000%
50%	4.62E+09	0.1225	0.410%	0	0.000%

Table C.20(b) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'k' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0	0.000%	0	0.000%
10%	1.85E+08	0.25	0.345%	0	0.000%
15%	4.16E+08	0.25	0.345%	0	0.000%
20%	7.40E+08	0.25	0.345%	0	0.000%
25%	1.16E+09	0.25	0.345%	0	0.000%
30%	1.66E+09	0.25	0.345%	0	0.000%
35%	2.27E+09	0.25	0.345%	0	0.000%
40%	2.96E+09	1	0.690%	0	0.000%
45%	3.75E+09	1	0.690%	0	0.000%
50%	4.62E+09	1	0.690%	0.25	0.278%

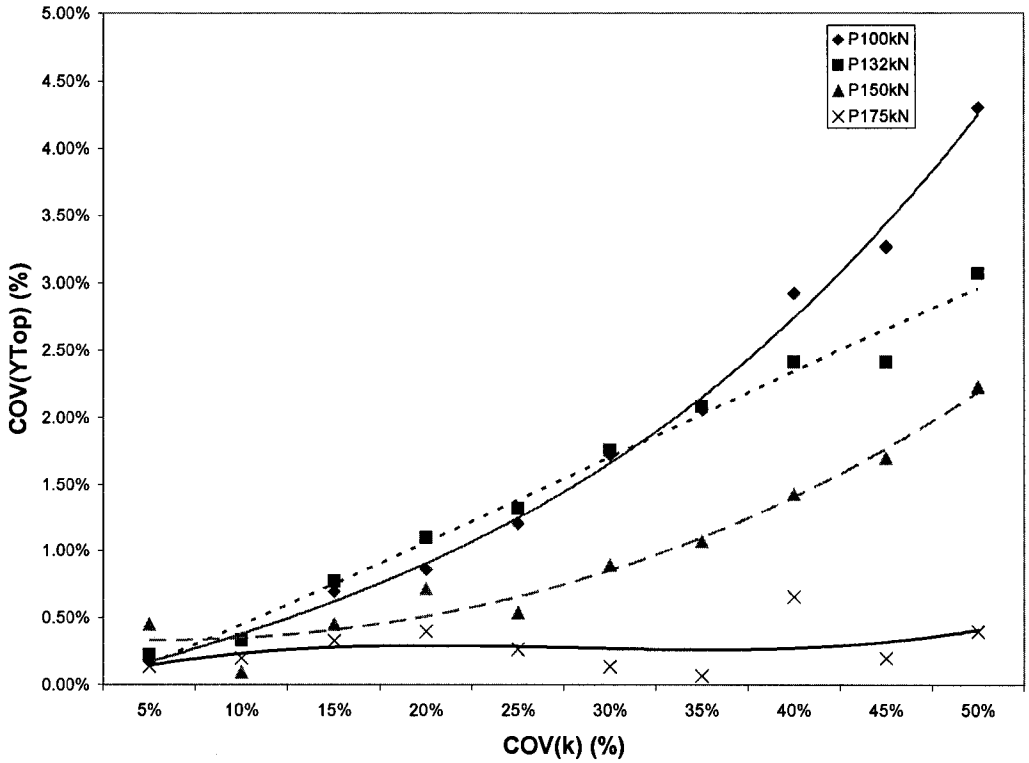

Fig. C.9 COV(Y_{Top}) for varying COV(k) in free head short pile (3T).

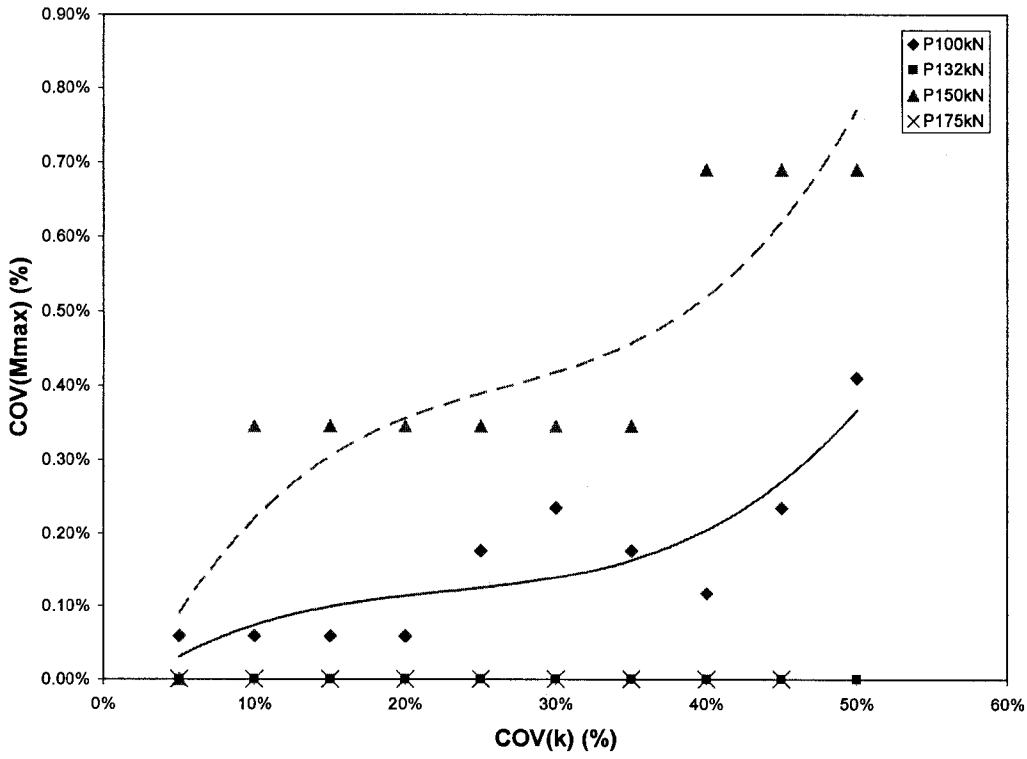

Fig. C.10 COV(M_{Max}) for varying COV(k) in free head short pile (3T).

C.1.6 Probabilistic modeling of laterally loaded free head single short pile (3T) with 'γ'' as varying random design variable

Following tables and figures shows the probabilistic modeling of laterally loaded free head single short pile with 'γ'' as varying random design variable and all the other random design variables are at their mean value.

Table C.21 Values of Y_{Top} for free head single short pile (3T) with varying 'γ'' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	8.7025	2.95	0.00292	0.00458	0.00563	0.00771
45%	7.049025	3.245	0.00292	0.00458	0.00563	0.0077
40%	5.5696	3.54	0.00292	0.00458	0.00563	0.0077
35%	4.264225	3.835	0.00291	0.00458	0.00563	0.0077
30%	3.1329	4.13	0.00291	0.00457	0.00563	0.00769
25%	2.175625	4.425	0.00291	0.00457	0.00562	0.00769
20%	1.3924	4.72	0.00291	0.00457	0.00562	0.00769
15%	0.783225	5.015	0.00291	0.00457	0.00562	0.00768
10%	0.3481	5.31	0.00291	0.00457	0.00562	0.00768
5%	0.087025	5.605	0.00291	0.00456	0.00561	0.00767
0%	0	5.9	0.00291	0.00456	0.00561	0.00767
5%	0.087025	6.195	0.00291	0.00456	0.00561	0.00767
10%	0.3481	6.49	0.0029	0.00456	0.00561	0.00766
15%	0.783225	6.785	0.0029	0.00456	0.00561	0.00766
20%	1.3924	7.08	0.0029	0.00456	0.0056	0.00766
25%	2.175625	7.375	0.0029	0.00455	0.0056	0.00765
30%	3.1329	7.67	0.0029	0.00455	0.0056	0.00765
35%	4.264225	7.965	0.0029	0.00455	0.0056	0.00765
40%	5.5696	8.26	0.0029	0.00455	0.0056	0.00764
45%	7.049025	8.555	0.0029	0.00455	0.00559	0.00764
50%	8.7025	8.85	0.0029	0.00454	0.00559	0.00764

Table C.22. Values of M_{Max} for free head single short pile (3T) with varying 'γ'' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	8.7025	2.95	85.5	122	145	180
45%	7.049025	3.245	85.5	122	145	180
40%	5.5696	3.54	85.5	122	145	180
35%	4.264225	3.835	85.4	122	145	180
30%	3.1329	4.13	85.4	122	145	180
25%	2.175625	4.425	85.4	122	145	180
20%	1.3924	4.72	85.4	122	145	180
15%	0.783225	5.015	85.4	122	145	180
10%	0.3481	5.31	85.4	122	145	180
5%	0.087025	5.605	85.4	122	145	180
0%	0	5.9	85.3	122	145	180
5%	0.087025	6.195	85.3	122	145	180
10%	0.3481	6.49	85.3	122	145	180
15%	0.783225	6.785	85.3	122	145	180
20%	1.3924	7.08	85.3	122	145	180
25%	2.175625	7.375	85.3	122	145	180
30%	3.1329	7.67	85.3	122	145	180
35%	4.264225	7.965	85.2	122	145	180
40%	5.5696	8.26	85.2	122	145	180
45%	7.049025	8.555	85.2	122	145	180
50%	8.7025	8.85	85.2	122	145	180

Table C.23(a) Value of COV (Y_{Top}) for free head single short pile (3T) with varying 'γ'' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0	0.000%	0.00E+00	0.000%
10%	0.3481	2.5E-11	0.172%	2.50E-11	0.110%
15%	0.783225	2.5E-11	0.172%	2.50E-11	0.110%
20%	1.3924	2.5E-11	0.172%	2.50E-11	0.110%
25%	2.175625	2.5E-11	0.172%	1.00E-10	0.219%
30%	3.1329	2.5E-11	0.172%	1.00E-10	0.219%
35%	4.264225	2.5E-11	0.172%	2.25E-10	0.329%
40%	5.5696	1E-10	0.344%	2.25E-10	0.329%
45%	7.049025	1E-10	0.344%	2.25E-10	0.329%
50%	8.7025	1E-10	0.344%	4.00E-10	0.439%

Table C.23(b) Value of COV(Y_{Top}) for free head single short pile (3T) with varying 'γ'' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	0.00E+00	0.000%
10%	0.3481	2.50E-11	0.089%	1.00E-10	0.130%
15%	0.783225	2.50E-11	0.089%	1.00E-10	0.130%
20%	1.3924	1.00E-10	0.178%	2.25E-10	0.196%
25%	2.175625	1.00E-10	0.178%	4.00E-10	0.261%
30%	3.1329	2.25E-10	0.267%	4.00E-10	0.261%
35%	4.264225	2.25E-10	0.267%	6.25E-10	0.326%
40%	5.5696	2.25E-10	0.267%	9.00E-10	0.391%
45%	7.049025	4.00E-10	0.357%	9.00E-10	0.391%
50%	8.7025	4.00E-10	0.357%	1.22E-09	0.456%

Table C.24(a) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'γ' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	0.087025	0.0025	0.059%	0	0.000%
10%	0.3481	0.0025	0.059%	0	0.000%
15%	0.783225	0.0025	0.059%	0	0.000%
20%	1.3924	0.0025	0.059%	0	0.000%
25%	2.175625	0.0025	0.059%	0	0.000%
30%	3.1329	0.0025	0.059%	0	0.000%
35%	4.264225	0.01	0.117%	0	0.000%
40%	5.5696	0.0225	0.176%	0	0.000%
45%	7.049025	0.0225	0.176%	0	0.000%
50%	8.7025	0.0225	0.176%	0	0.000%

Table C.24(b) Value of COV(M_{Max}) for free head single short pile (3T) with varying 'γ' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	0.087025	0	0.000%	0	0.000%
10%	0.3481	0	0.000%	0	0.000%
15%	0.783225	0	0.000%	0	0.000%
20%	1.3924	0	0.000%	0	0.000%
25%	2.175625	0	0.000%	0	0.000%
30%	3.1329	0	0.000%	0	0.000%
35%	4.264225	0	0.000%	0	0.000%
40%	5.5696	0	0.000%	0	0.000%
45%	7.049025	0	0.000%	0	0.000%
50%	8.7025	0	0.000%	0	0.000%

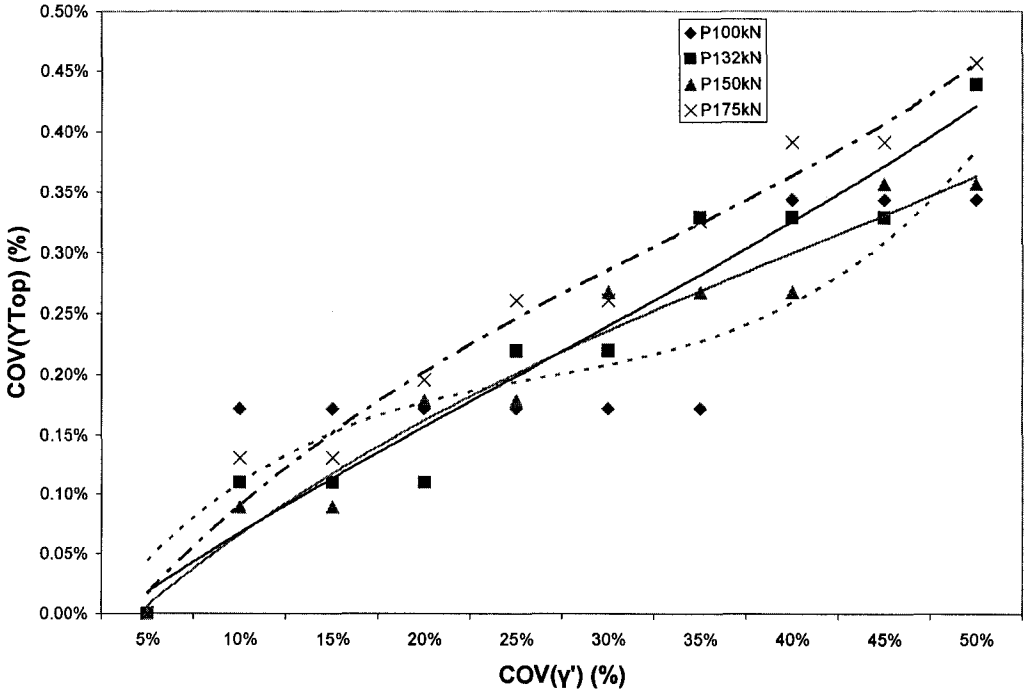

Fig. C.11 COV(Y_{Top}) for varying COV(γ') in free head short pile (3T).

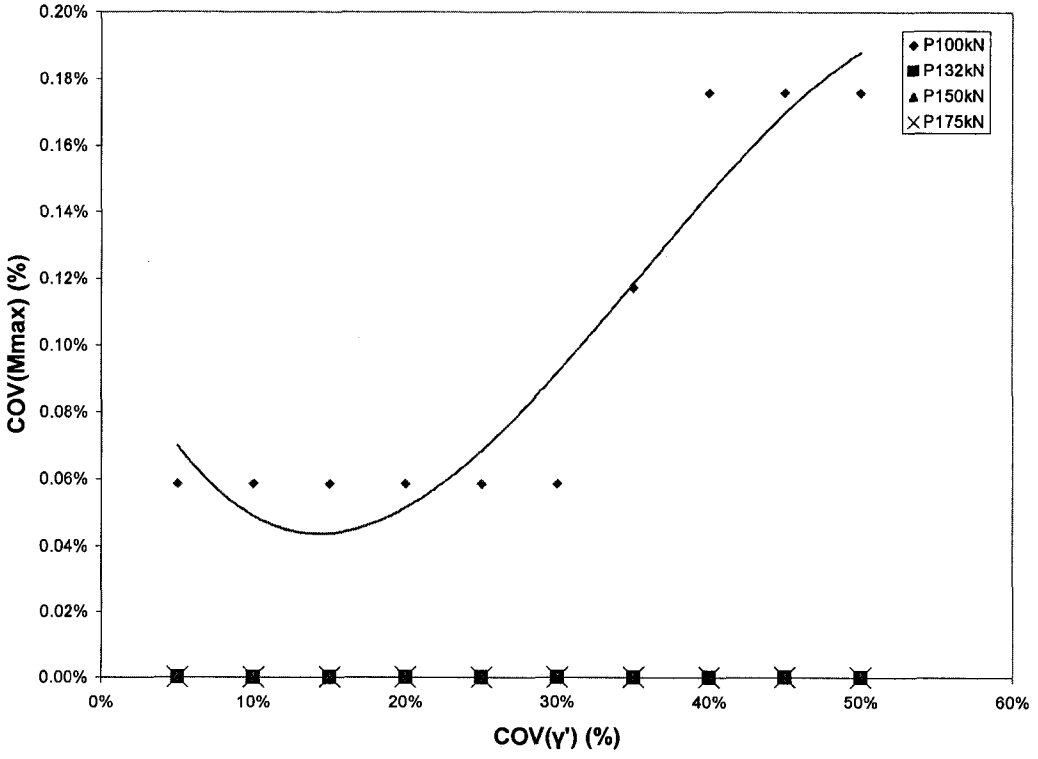

Fig. C.12 COV(M_{Max}) for varying COV(γ') in free head short pile (3T).

C.2 Reliability analysis of free head single short pile.

C.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 100 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.0101m \quad \text{and} \quad VAR(Y_{top}^{Resist}) = 7E\text{-}06\ m^2$$

Table C.25 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 100 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	3.88	1.96E-08	6.78E-06	3.88
10%	6.76E-06	0.00E+00	6.76E-06	3.88	7.84E-08	6.84E-06	3.86
15%	6.76E-06	2.50E-11	6.76E-06	3.88	1.85E-07	6.94E-06	3.83
20%	6.76E-06	0.00E+00	6.76E-06	3.88	3.31E-07	7.09E-06	3.79
25%	6.76E-06	2.50E-11	6.76E-06	3.88	5.26E-07	7.29E-06	3.74
30%	6.76E-06	1.00E-10	6.76E-06	3.88	7.92E-07	7.55E-06	3.67
35%	6.76E-06	4.00E-10	6.76E-06	3.88	1.22E-06	7.98E-06	3.57
40%	6.76E-06	2.03E-09	6.76E-06	3.88	1.96E-06	8.72E-06	3.42
45%	6.76E-06	5.63E-09	6.77E-06	3.88	2.86E-06	9.62E-06	3.25
50%	6.76E-06	1.21E-08	6.77E-06	3.88	4.08E-06	1.08E-05	3.06

Table C.26 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 100 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	3.02E-09	6.76E-06	3.88	1.60E-09	6.76E-06	3.88
10%	6.76E-06	1.32E-08	6.77E-06	3.88	6.40E-09	6.77E-06	3.88
15%	6.76E-06	2.89E-08	6.79E-06	3.87	1.56E-08	6.78E-06	3.88
20%	6.76E-06	5.29E-08	6.81E-06	3.87	1.48E-07	6.91E-06	3.84
25%	6.76E-06	8.12E-08	6.84E-06	3.86	3.14E-07	7.07E-06	3.79
30%	6.76E-06	1.19E-07	6.88E-06	3.85	3.78E-07	7.14E-06	3.78
35%	6.76E-06	1.60E-07	6.92E-06	3.84	4.42E-07	7.20E-06	3.76
40%	6.76E-06	2.07E-07	6.97E-06	3.82	5.26E-07	7.29E-06	3.74
45%	6.76E-06	2.55E-07	7.02E-06	3.81	6.16E-07	7.38E-06	3.72
50%	6.76E-06	3.14E-07	7.07E-06	3.79	7.31E-07	7.49E-06	3.69

Table C.27 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 100 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.88	2.50E-11	6.76E-06	3.88
10%	6.76E-06	2.50E-11	6.76E-06	3.88	1.00E-10	6.76E-06	3.88
15%	6.76E-06	2.50E-11	6.76E-06	3.88	4.00E-10	6.76E-06	3.88
20%	6.76E-06	2.50E-11	6.76E-06	3.88	6.25E-10	6.76E-06	3.88
25%	6.76E-06	2.50E-11	6.76E-06	3.88	1.22E-09	6.76E-06	3.88
30%	6.76E-06	2.50E-11	6.76E-06	3.88	2.50E-09	6.76E-06	3.88
35%	6.76E-06	2.50E-11	6.76E-06	3.88	3.60E-09	6.76E-06	3.88
40%	6.76E-06	1.00E-10	6.76E-06	3.88	7.23E-09	6.77E-06	3.88
45%	6.76E-06	1.00E-10	6.76E-06	3.88	9.02E-09	6.77E-06	3.88
50%	6.76E-06	1.00E-10	6.76E-06	3.88	1.56E-08	6.78E-06	3.88

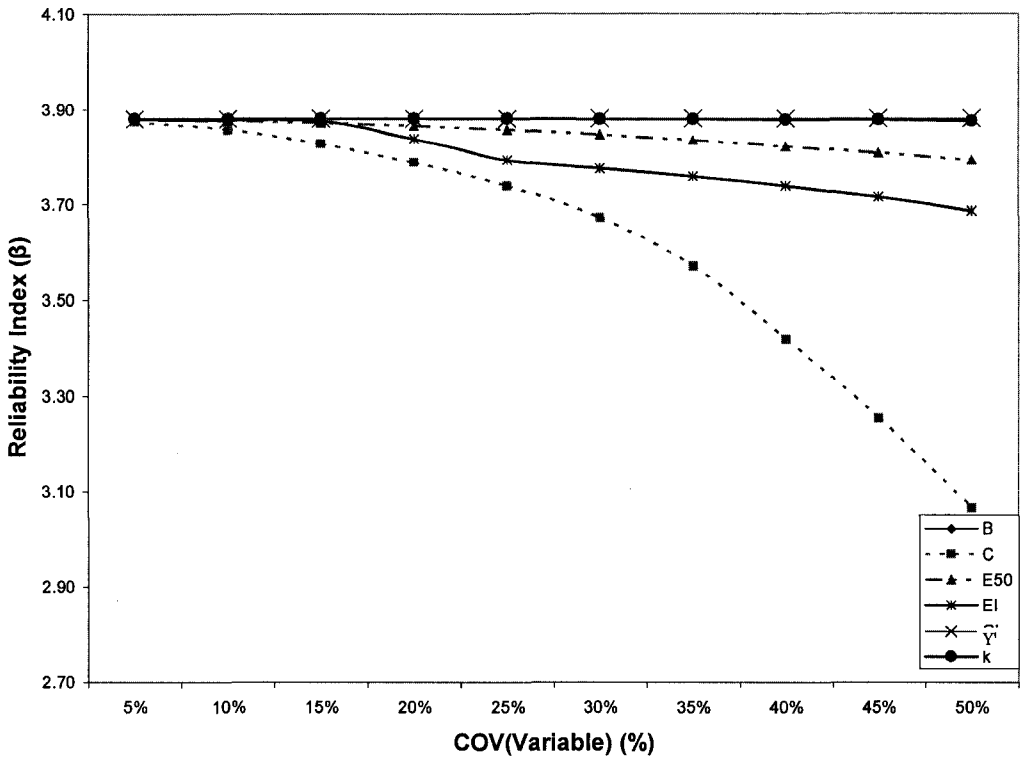

Fig. C.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single short pile (3T) at 100 kN lateral load.

For lateral load 132 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.0084m$$

Table C.28 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 132 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	3.25	5.06E-08	6.81E-06	3.23
10%	6.76E-06	4.00E-10	6.76E-06	3.25	2.03E-07	6.96E-06	3.20
15%	6.76E-06	4.00E-10	6.76E-06	3.25	5.18E-07	7.28E-06	3.13
20%	6.76E-06	9.00E-10	6.76E-06	3.25	1.04E-06	7.80E-06	3.02
25%	6.76E-06	2.50E-09	6.76E-06	3.25	1.82E-06	8.58E-06	2.88
30%	6.76E-06	4.90E-09	6.76E-06	3.24	2.84E-06	9.60E-06	2.72
35%	6.76E-06	1.00E-08	6.77E-06	3.24	4.49E-06	1.13E-05	2.52
40%	6.76E-06	3.61E-08	6.80E-06	3.24	6.76E-06	1.35E-05	2.30
45%	6.76E-06	9.92E-08	6.86E-06	3.22	9.89E-06	1.67E-05	2.07
50%	6.76E-06	2.40E-07	7.00E-06	3.19	1.50E-05	2.17E-05	1.81

Table C.29 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 132 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	6.40E-09	6.77E-06	3.24	4.22E-09	6.76E-06	3.25
10%	6.76E-06	2.56E-08	6.79E-06	3.24	1.96E-08	6.78E-06	3.24
15%	6.76E-06	5.76E-08	6.82E-06	3.23	4.41E-08	6.80E-06	3.24
20%	6.76E-06	1.06E-07	6.87E-06	3.22	3.97E-07	7.16E-06	3.15
25%	6.76E-06	1.60E-07	6.92E-06	3.21	8.74E-07	7.63E-06	3.05
30%	6.76E-06	2.35E-07	7.00E-06	3.19	1.03E-06	7.79E-06	3.02
35%	6.76E-06	3.14E-07	7.07E-06	3.17	1.21E-06	7.97E-06	2.99
40%	6.76E-06	4.16E-07	7.18E-06	3.15	1.43E-06	8.19E-06	2.95
45%	6.76E-06	5.18E-07	7.28E-06	3.13	1.78E-06	8.54E-06	2.89
50%	6.76E-06	6.08E-07	7.37E-06	3.11	2.10E-06	8.86E-06	2.84

Table C.30 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 132 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.25	1.00E-10	6.76E-06	3.25
10%	6.76E-06	2.50E-11	6.76E-06	3.25	2.25E-10	6.76E-06	3.25
15%	6.76E-06	2.50E-11	6.76E-06	3.25	1.23E-09	6.76E-06	3.25
20%	6.76E-06	2.50E-11	6.76E-06	3.25	2.50E-09	6.76E-06	3.25
25%	6.76E-06	1.00E-10	6.76E-06	3.25	3.60E-09	6.76E-06	3.25
30%	6.76E-06	1.00E-10	6.76E-06	3.25	6.40E-09	6.77E-06	3.24
35%	6.76E-06	2.25E-10	6.76E-06	3.25	9.03E-09	6.77E-06	3.24
40%	6.76E-06	2.25E-10	6.76E-06	3.25	1.21E-08	6.77E-06	3.24
45%	6.76E-06	2.25E-10	6.76E-06	3.25	1.21E-08	6.77E-06	3.24
50%	6.76E-06	4.00E-10	6.76E-06	3.25	1.96E-08	6.78E-06	3.24

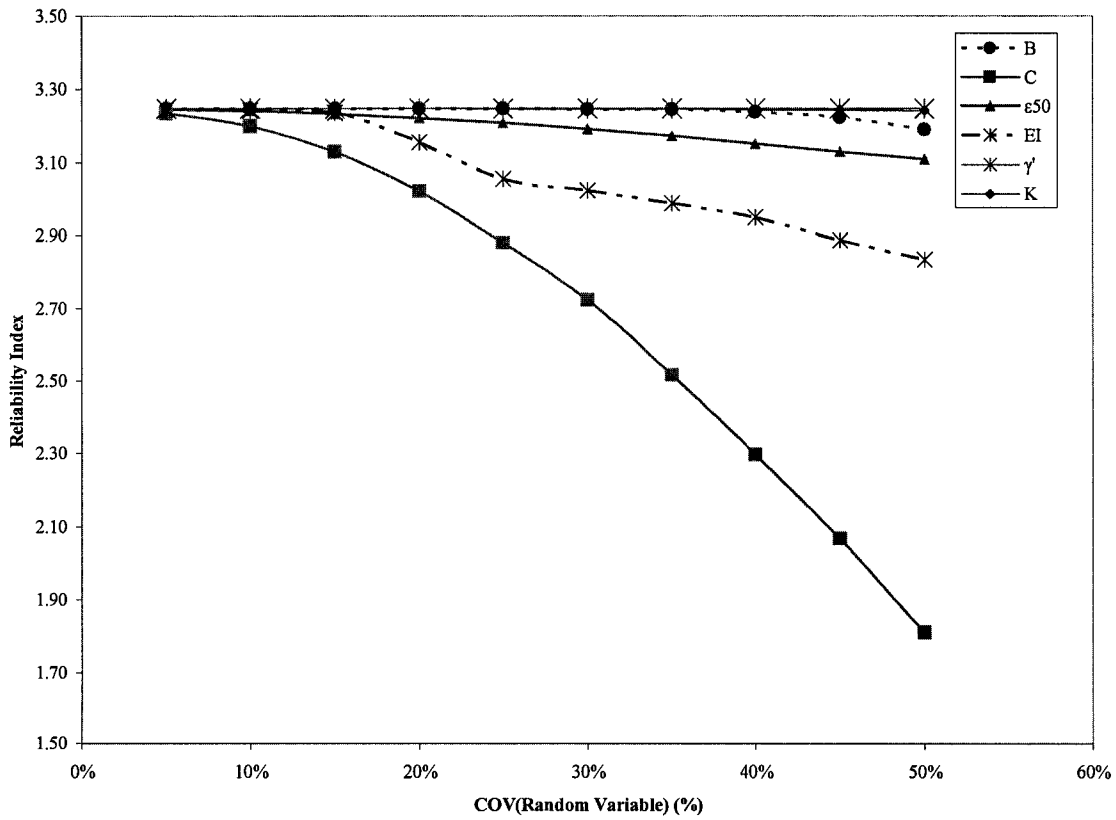

Fig. C.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single short pile (3T) at 132 kN lateral load.

For lateral load 150 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.0074m$$

Table C.31 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 150 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	2.84	1.23E-07	6.88E-06	2.82
10%	6.76E-06	4.22E-09	6.76E-06	2.84	4.23E-07	7.18E-06	2.76
15%	6.76E-06	6.40E-09	6.77E-06	2.84	1.05E-06	7.81E-06	2.64
20%	6.76E-06	2.10E-08	6.78E-06	2.84	1.92E-06	8.68E-06	2.51
25%	6.76E-06	3.42E-08	6.79E-06	2.84	3.33E-06	1.01E-05	2.33
30%	6.76E-06	6.50E-08	6.83E-06	2.83	5.36E-06	1.21E-05	2.12
35%	6.76E-06	1.19E-07	6.88E-06	2.82	8.12E-06	1.49E-05	1.92
40%	6.76E-06	2.45E-07	7.01E-06	2.79	1.25E-05	1.93E-05	1.68
45%	6.76E-06	4.76E-07	7.24E-06	2.75	1.96E-05	2.63E-05	1.44
50%	6.76E-06	1.13E-06	7.89E-06	2.63	3.23E-05	3.91E-05	1.18

Table C.32 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 150 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	8.10E-09	6.77E-06	2.84	7.23E-09	6.77E-06	2.84
10%	6.76E-06	3.24E-08	6.79E-06	2.84	2.89E-08	6.79E-06	2.84
15%	6.76E-06	9.30E-08	6.85E-06	2.82	9.00E-08	6.85E-06	2.82
20%	6.76E-06	1.60E-07	6.92E-06	2.81	8.28E-07	7.59E-06	2.68
25%	6.76E-06	2.40E-07	7.00E-06	2.79	1.73E-06	8.49E-06	2.54
30%	6.76E-06	3.36E-07	7.10E-06	2.77	2.06E-06	8.82E-06	2.49
35%	6.76E-06	4.49E-07	7.21E-06	2.75	2.43E-06	9.19E-06	2.44
40%	6.76E-06	5.78E-07	7.34E-06	2.73	2.87E-06	9.63E-06	2.38
45%	6.76E-06	7.23E-07	7.48E-06	2.70	3.39E-06	1.01E-05	2.32
50%	6.76E-06	8.01E-07	7.56E-06	2.69	4.02E-06	1.08E-05	2.25

Table C.33 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 150 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.84	6.25E-10	6.76E-06	2.84
10%	6.76E-06	2.50E-11	6.76E-06	2.84	2.50E-11	6.76E-06	2.84
15%	6.76E-06	2.50E-11	6.76E-06	2.84	6.25E-10	6.76E-06	2.84
20%	6.76E-06	1.00E-10	6.76E-06	2.84	1.60E-09	6.76E-06	2.84
25%	6.76E-06	1.00E-10	6.76E-06	2.84	9.00E-10	6.76E-06	2.84
30%	6.76E-06	2.25E-10	6.76E-06	2.84	2.50E-09	6.76E-06	2.84
35%	6.76E-06	2.25E-10	6.76E-06	2.84	3.60E-09	6.76E-06	2.84
40%	6.76E-06	2.25E-10	6.76E-06	2.84	6.40E-09	6.77E-06	2.84
45%	6.76E-06	4.00E-10	6.76E-06	2.84	9.03E-09	6.77E-06	2.84
50%	6.76E-06	4.00E-10	6.76E-06	2.84	1.56E-08	6.78E-06	2.84

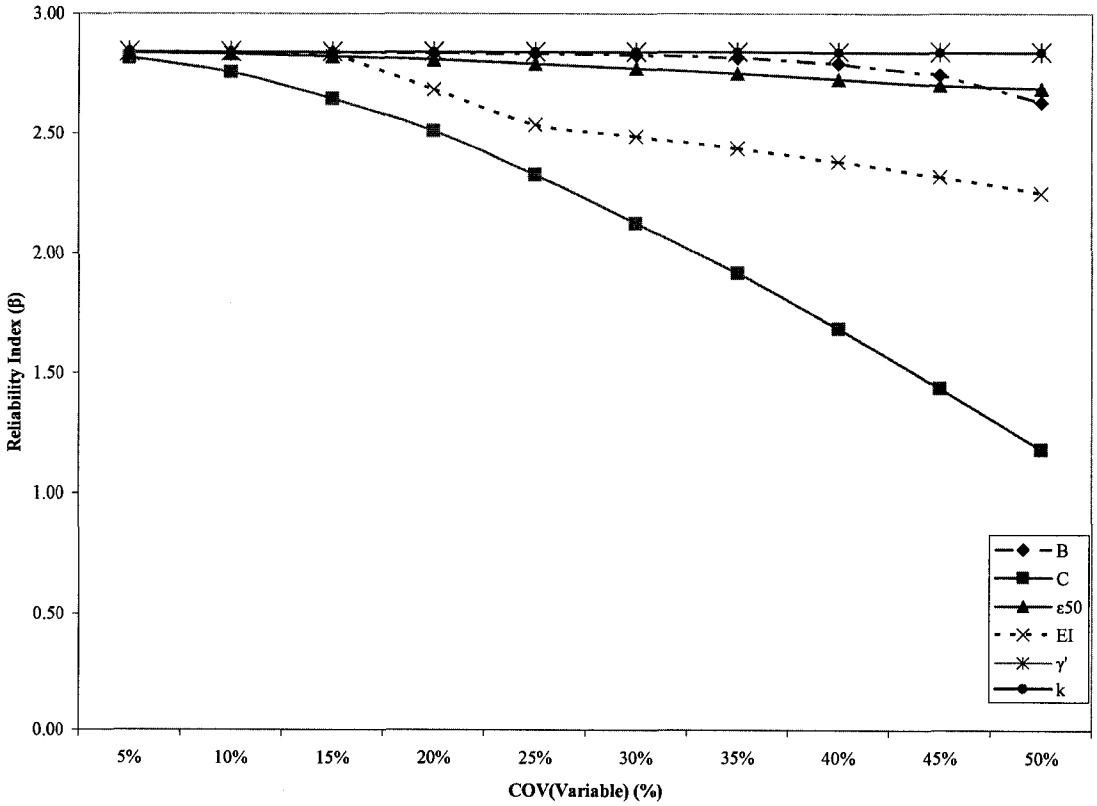

Fig. C.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single short pile (3T) at 150 kN lateral load.

For lateral load 175 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.0053m$$

Table C.34 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 175 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-09	6.76E-06	2.05	2.45E-07	7.01E-06	2.01
10%	6.76E-06	1.21E-08	6.77E-06	2.05	1.00E-06	7.76E-06	1.91
15%	6.76E-06	4.20E-08	6.80E-06	2.04	2.45E-06	9.21E-06	1.76
20%	6.76E-06	8.41E-08	6.84E-06	2.04	4.43E-06	1.12E-05	1.59
25%	6.76E-06	1.81E-07	6.94E-06	2.02	7.65E-06	1.44E-05	1.40
30%	6.76E-06	3.72E-07	7.13E-06	2.00	1.21E-05	1.89E-05	1.23
35%	6.76E-06	7.40E-07	7.50E-06	1.95	1.93E-05	2.60E-05	1.04
40%	6.76E-06	1.51E-06	8.27E-06	1.85	3.18E-05	3.86E-05	0.86
45%	6.76E-06	4.02E-06	1.08E-05	1.62	5.83E-05	6.51E-05	0.66
50%	6.76E-06	1.36E-05	2.03E-05	1.18	5.93E-06	1.27E-05	Failed

Table C.35 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 175 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.21E-08	6.77E-06	2.05	1.82E-08	6.78E-06	2.05
10%	6.76E-06	5.06E-08	6.81E-06	2.04	7.02E-08	6.83E-06	2.04
15%	6.76E-06	1.12E-07	6.87E-06	2.03	1.60E-07	6.92E-06	2.03
20%	6.76E-06	2.03E-07	6.96E-06	2.02	1.70E-06	8.46E-06	1.83
25%	6.76E-06	3.14E-07	7.07E-06	2.00	3.69E-06	1.04E-05	1.65
30%	6.76E-06	4.56E-07	7.22E-06	1.98	4.45E-06	1.12E-05	1.59
35%	6.76E-06	6.08E-07	7.37E-06	1.96	5.29E-06	1.21E-05	1.54
40%	6.76E-06	7.92E-07	7.55E-06	1.94	6.18E-06	1.29E-05	1.48
45%	6.76E-06	9.80E-07	7.74E-06	1.92	7.40E-06	1.42E-05	1.42
50%	6.76E-06	1.18E-06	7.94E-06	1.89	9.00E-06	1.58E-05	1.34

Table C.36 Reliability Index connected to Y_{Top} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 175 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.05	1.00E-10	6.76E-06	2.05
10%	6.76E-06	1.00E-10	6.76E-06	2.05	2.25E-10	6.76E-06	2.05
15%	6.76E-06	1.00E-10	6.76E-06	2.05	6.25E-10	6.76E-06	2.05
20%	6.76E-06	2.25E-10	6.76E-06	2.05	9.00E-10	6.76E-06	2.05
25%	6.76E-06	4.00E-10	6.76E-06	2.05	4.00E-10	6.76E-06	2.05
30%	6.76E-06	4.00E-10	6.76E-06	2.05	1.00E-10	6.76E-06	2.05
35%	6.76E-06	6.25E-10	6.76E-06	2.05	2.50E-11	6.76E-06	2.05
40%	6.76E-06	9.00E-10	6.76E-06	2.05	2.50E-09	6.76E-06	2.05
45%	6.76E-06	9.00E-10	6.76E-06	2.05	2.25E-10	6.76E-06	2.05
50%	6.76E-06	1.22E-09	6.76E-06	2.05	9.00E-10	6.76E-06	2.05

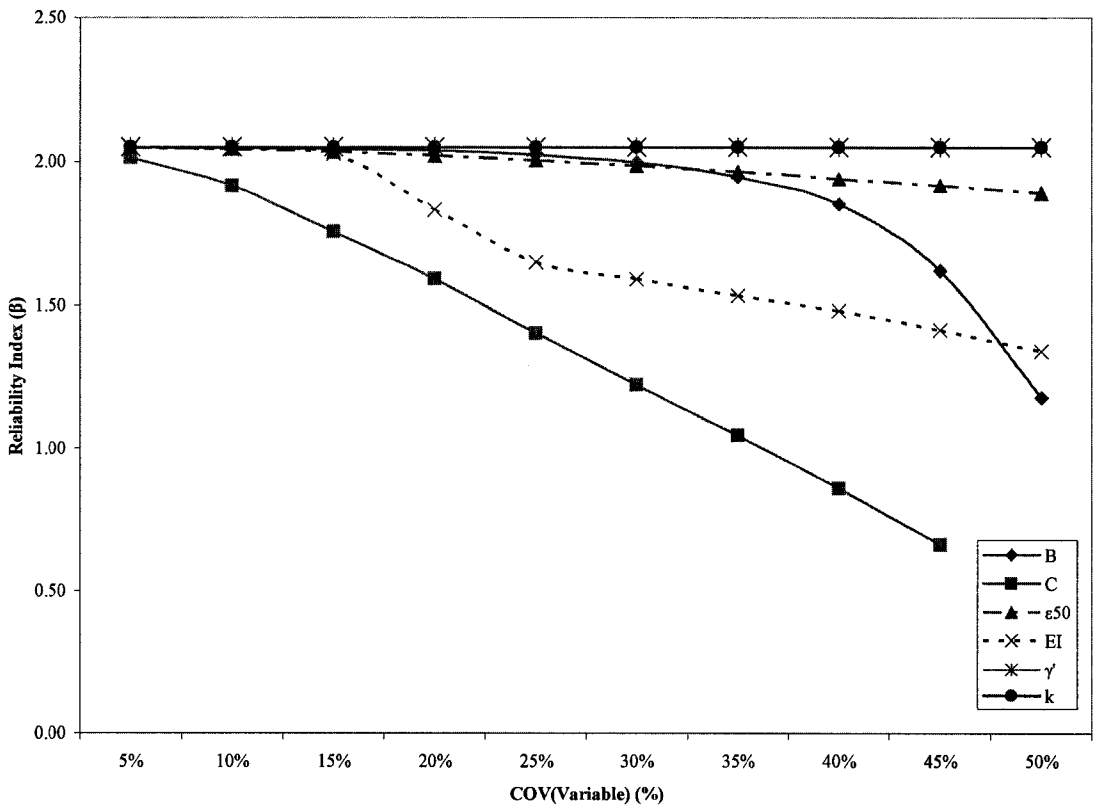

Fig. C.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single short pile (3T) at 175 kN lateral load.

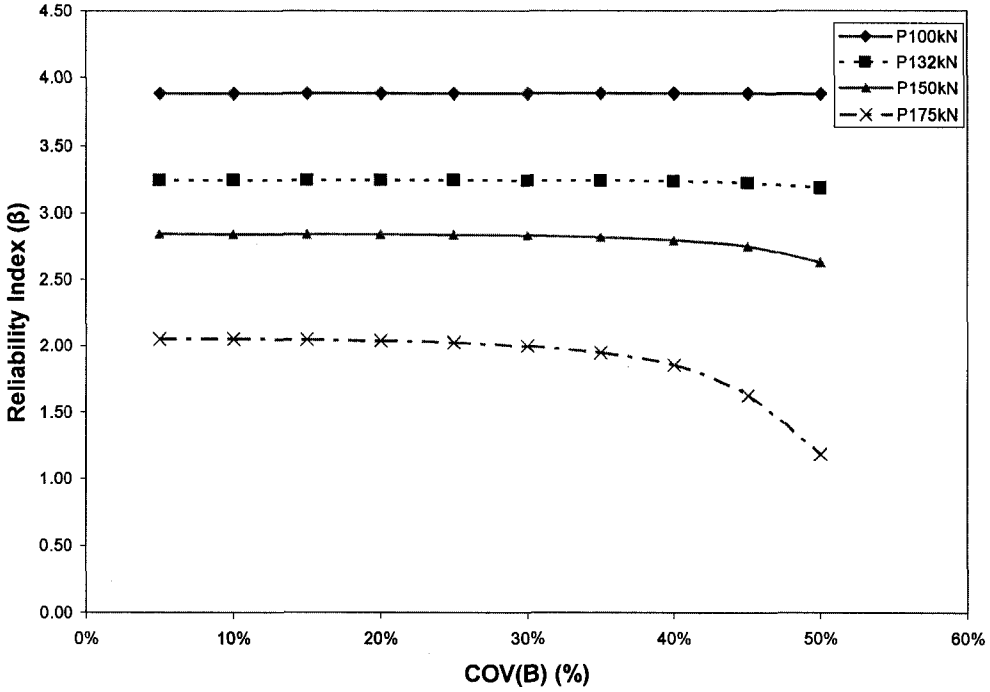

Fig. C.17 Reliability Index related to Y_{Top} for free head short pile with varying 'B'.

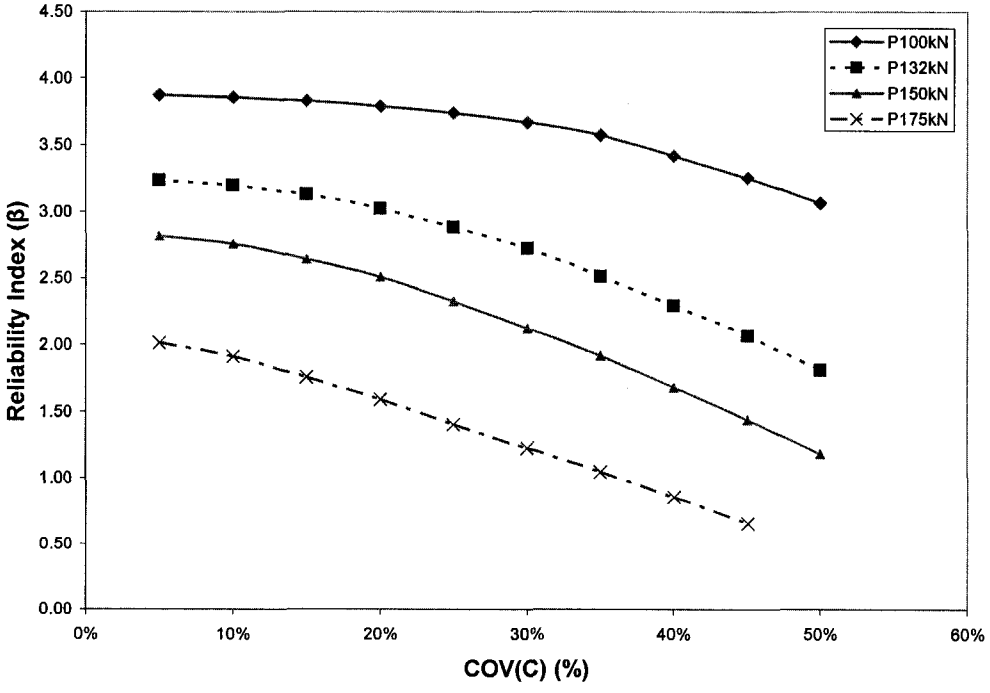

Fig. C.18 Reliability Index related to Y_{Top} for free head short pile with varying 'C'.

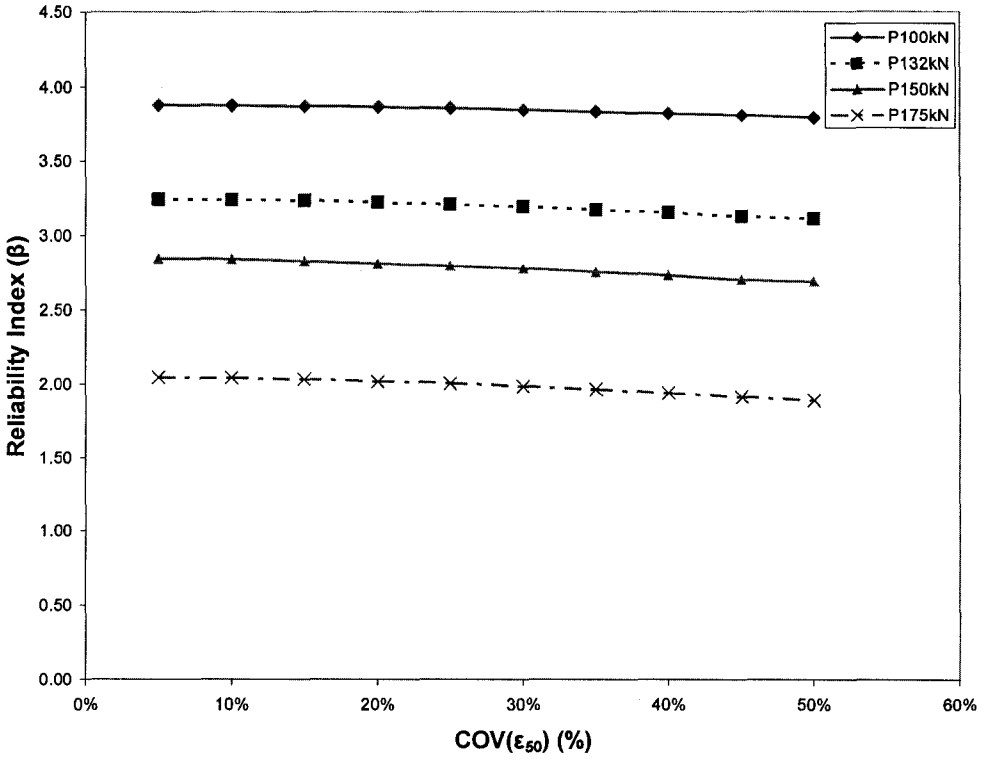

Fig. C.19 Reliability Index related to Y_{Top} for free head short pile with varying 'ε_{50}'.

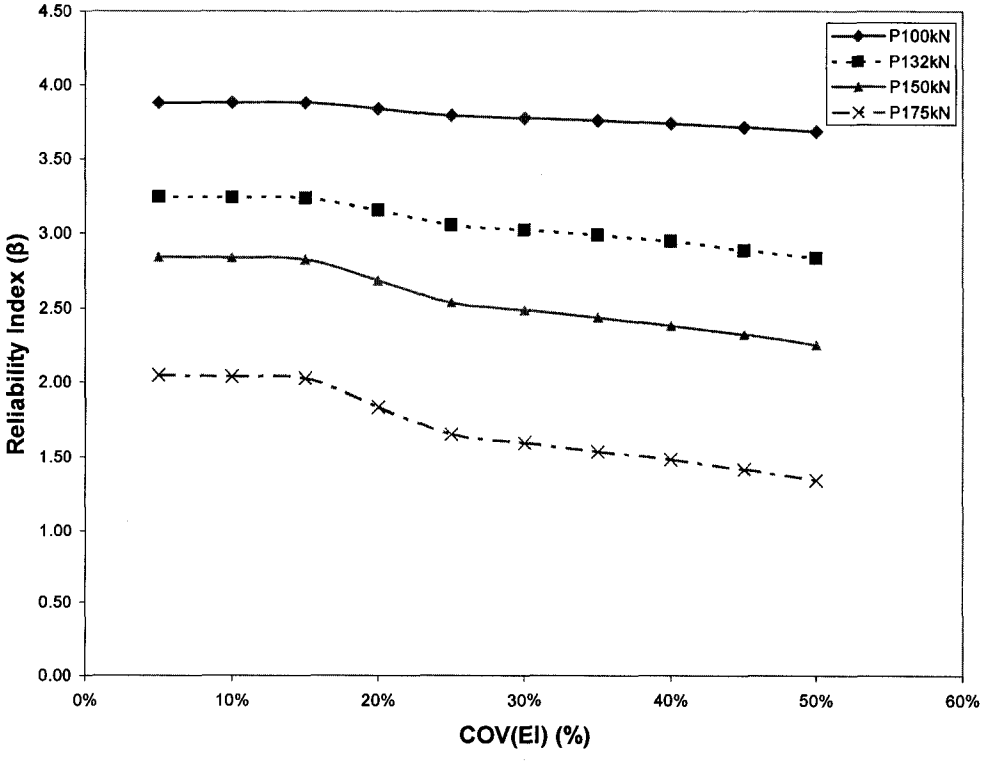

Fig. C.20 Reliability Index related to Y_{Top} for free head short pile with varying 'EI'.

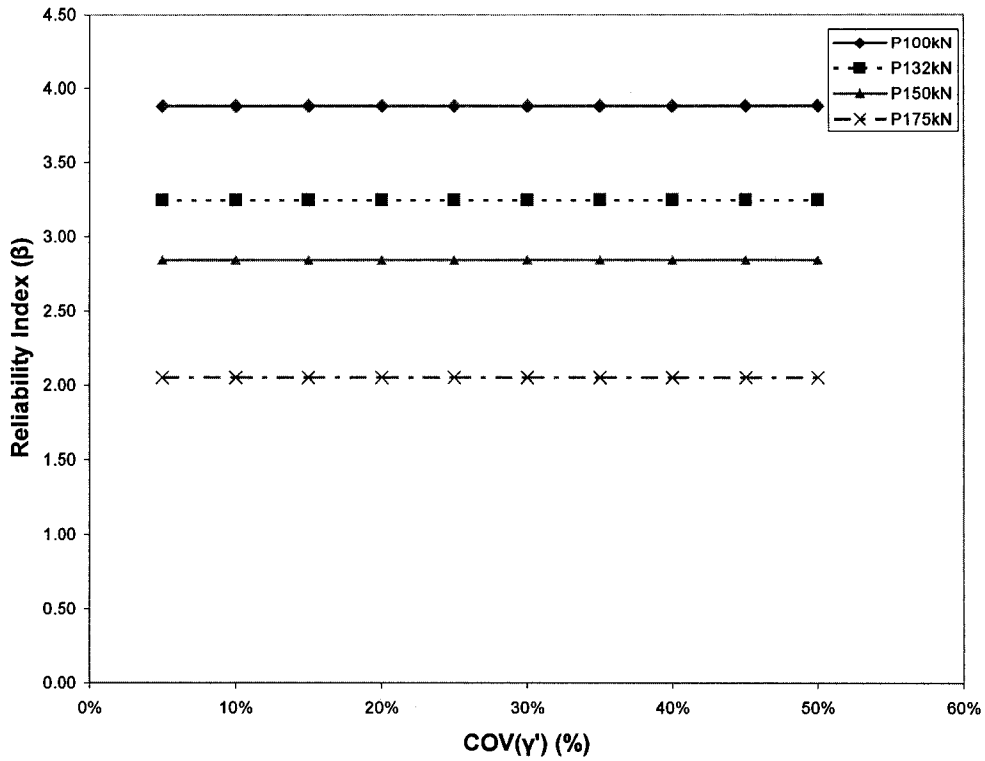

Fig. C.21 Reliability Index related to Y_{Top} for free head short pile with varying 'γ'.

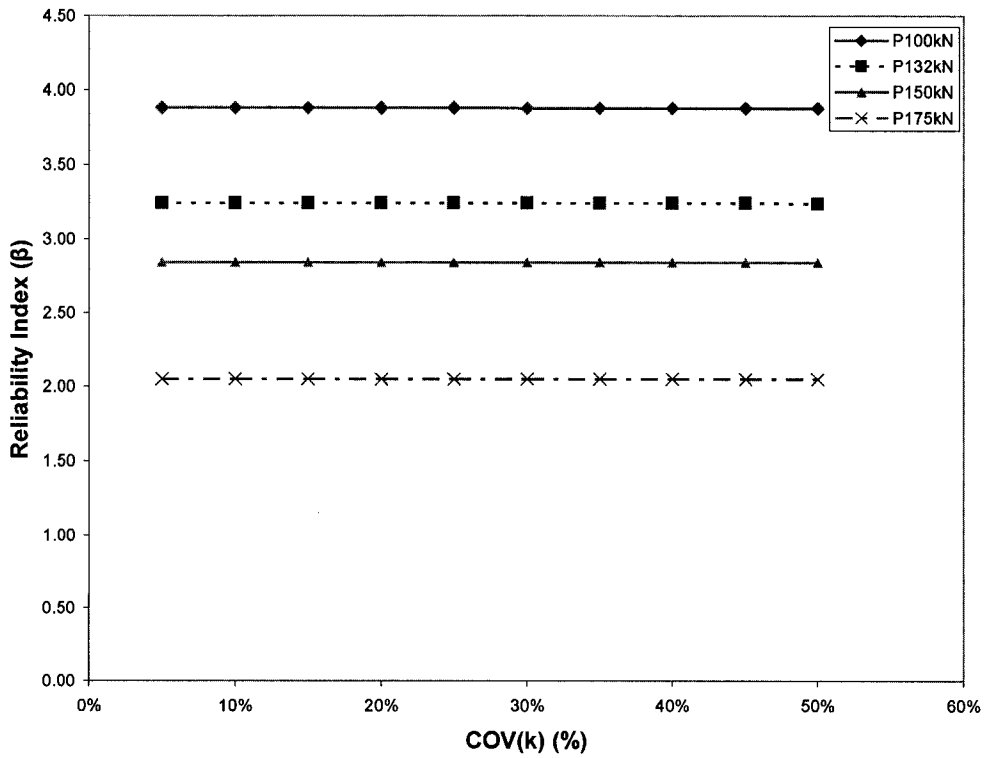

Fig. C.22 Reliability Index related to Y_{Top} for free head short pile with varying 'k'.

C.2.1 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 100 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 808.70 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table C.37 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 100 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) (kN-m)^2	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)
5%	31969.44	0	31969.440	4.52	2.4025	31971.843	4.52
10%	31969.44	0	31969.440	4.52	9.61	31979.050	4.52
15%	31969.44	0	31969.440	4.52	21.16	31990.600	4.52
20%	31969.44	0	31969.440	4.52	37.8225	32007.263	4.52
25%	31969.44	0	31969.440	4.52	66.4225	32035.863	4.52
30%	31969.44	0	31969.440	4.52	85.5625	32055.003	4.52
35%	31969.44	0	31969.440	4.52	128.8225	32098.263	4.51
40%	31969.44	0	31969.440	4.52	198.81	32168.250	4.51
45%	31969.44	0.01	31969.450	4.52	268.96	32238.400	4.50
50%	31969.44	0.0625	31969.503	4.52	368.64	32338.080	4.50

Table C.38 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 100 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.25	31969.690	4.52	0.0625	31969.503	4.52
10%	31969.44	0.9025	31970.343	4.52	0.3025	31969.743	4.52
15%	31969.44	2.1025	31971.543	4.52	0.64	31970.080	4.52
20%	31969.44	3.61	31973.050	4.52	4	31973.440	4.52
25%	31969.44	5.76	31975.200	4.52	10.24	31979.680	4.52
30%	31969.44	8.1225	31977.563	4.52	11.9025	31981.343	4.52
35%	31969.44	11.56	31981.000	4.52	13.69	31983.130	4.52
40%	31969.44	15.6025	31985.043	4.52	16	31985.440	4.52
45%	31969.44	19.8025	31989.243	4.52	18.0625	31987.503	4.52
50%	31969.44	24.5025	31993.943	4.52	20.7025	31990.143	4.52

Table C.39 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 100 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.443	4.52	0.0025	31969.443	4.52
10%	31969.44	0.0025	31969.443	4.52	0.0025	31969.443	4.52
15%	31969.44	0.0025	31969.443	4.52	0.0025	31969.443	4.52
20%	31969.44	0.0025	31969.443	4.52	0.0025	31969.443	4.52
25%	31969.44	0.0025	31969.443	4.52	0.0225	31969.463	4.52
30%	31969.44	0.0025	31969.443	4.52	0.04	31969.480	4.52
35%	31969.44	0.01	31969.450	4.52	0.0225	31969.463	4.52
40%	31969.44	0.0225	31969.463	4.52	0.01	31969.450	4.52
45%	31969.44	0.0225	31969.463	4.52	0.04	31969.480	4.52
50%	31969.44	0.0225	31969.463	4.52	0.1225	31969.563	4.52

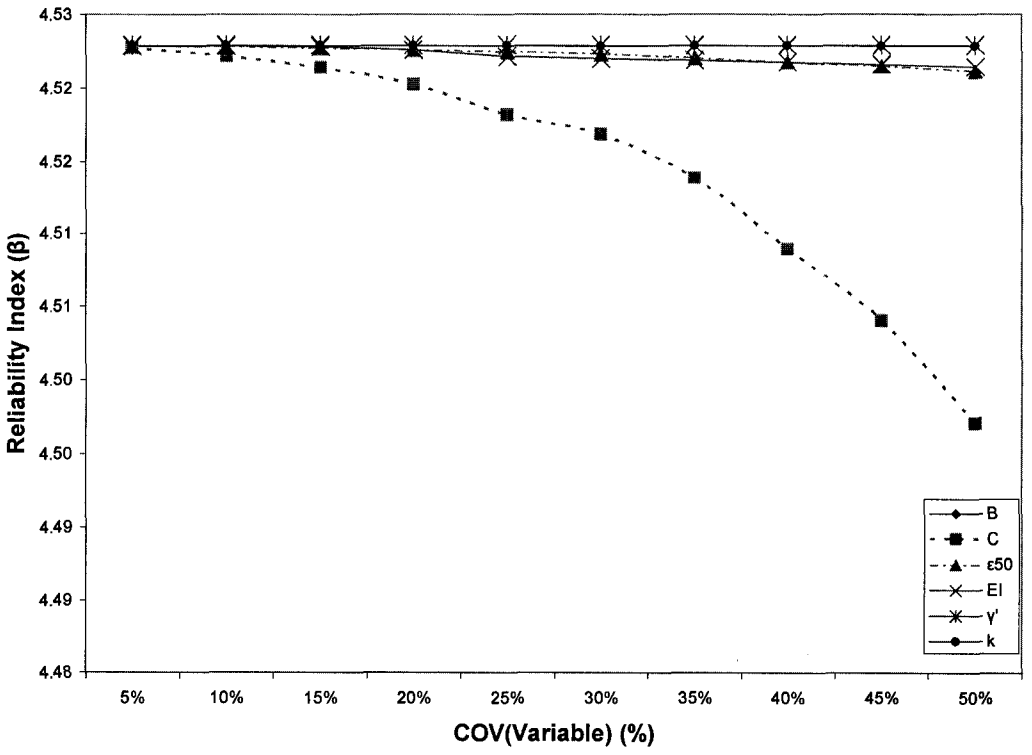

Fig. C.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single short pile (3T) at 100 kN lateral load.

For lateral load 132 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 772 \text{ kN.m}$$

Table C.40 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 132 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.32	6.25	31975.69	4.32
10%	31969.44	0.25	31969.69	4.32	25	31994.44	4.32
15%	31969.44	0.25	31969.69	4.32	56.25	32025.69	4.31
20%	31969.44	0.25	31969.69	4.32	90.25	32059.69	4.31
25%	31969.44	0.25	31969.69	4.32	169	32138.44	4.31
30%	31969.44	0.25	31969.69	4.32	256	32225.44	4.30
35%	31969.44	1	31970.44	4.32	380.25	32349.69	4.29
40%	31969.44	1	31970.44	4.32	552.25	32521.69	4.28
45%	31969.44	4	31973.44	4.32	729	32698.44	4.27
50%	31969.44	12.25	31981.69	4.32	992.25	32961.69	4.25

Table C.41 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 132 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.25	31969.69	4.32	0	31969.44	4.32
10%	31969.44	1	31970.44	4.32	0.25	31969.69	4.32
15%	31969.44	1	31970.44	4.32	0.25	31969.69	4.32
20%	31969.44	4	31973.44	4.32	4	31973.44	4.32
25%	31969.44	4	31973.44	4.32	9	31978.44	4.32
30%	31969.44	9	31978.44	4.32	9	31978.44	4.32
35%	31969.44	9	31978.44	4.32	16	31985.44	4.32
40%	31969.44	12.25	31981.69	4.32	16	31985.44	4.32
45%	31969.44	16	31985.44	4.32	20.25	31989.69	4.32
50%	31969.44	20.25	31989.69	4.32	20.25	31989.69	4.32

Table C.42 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 132 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.32	0	31969.44	4.32
10%	31969.44	0	31969.44	4.32	0	31969.44	4.32
15%	31969.44	0	31969.44	4.32	0	31969.44	4.32
20%	31969.44	0	31969.44	4.32	0	31969.44	4.32
25%	31969.44	0	31969.44	4.32	0	31969.44	4.32
30%	31969.44	0	31969.44	4.32	0	31969.44	4.32
35%	31969.44	0	31969.44	4.32	0	31969.44	4.32
40%	31969.44	0	31969.44	4.32	0	31969.44	4.32
45%	31969.44	0	31969.44	4.32	0	31969.44	4.32
50%	31969.44	0	31969.44	4.32	0	31969.44	4.32

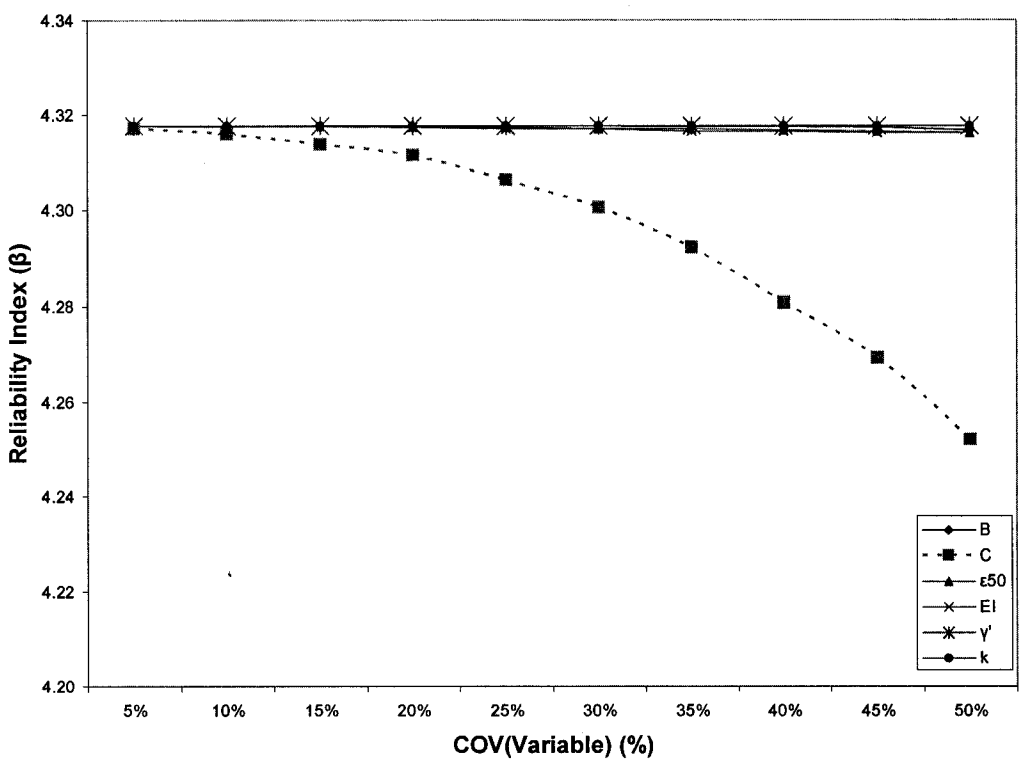

Fig. C.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single short pile (3T) at 132 kN lateral load.

For lateral load 150 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 749 \text{ kN.m}$$

Table C.43 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 150 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.19	9	31978.44	4.19
10%	31969.44	0	31969.44	4.19	36	32005.44	4.19
15%	31969.44	0.25	31969.69	4.19	90.25	32059.69	4.18
20%	31969.44	0.25	31969.69	4.19	169	32138.44	4.18
25%	31969.44	0.25	31969.69	4.19	272.25	32241.69	4.17
30%	31969.44	2.25	31971.69	4.19	420.25	32389.69	4.16
35%	31969.44	6.25	31975.69	4.19	600.25	32569.69	4.15
40%	31969.44	12.25	31981.69	4.19	870.25	32839.69	4.13
45%	31969.44	20.25	31989.69	4.19	1260.25	33229.69	4.11
50%	31969.44	64	32033.44	4.18	1806.25	33775.69	4.08

Table C.44 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 150 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.25	31969.69	4.19	0	31969.44	4.19
10%	31969.44	1	31970.44	4.19	0.25	31969.69	4.19
15%	31969.44	1	31970.44	4.19	1	31970.44	4.19
20%	31969.44	2.25	31971.69	4.19	4	31973.44	4.19
25%	31969.44	2.25	31971.69	4.19	9	31978.44	4.19
30%	31969.44	4	31973.44	4.19	12.25	31981.69	4.19
35%	31969.44	6.25	31975.69	4.19	12.25	31981.69	4.19
40%	31969.44	9	31978.44	4.19	12.25	31981.69	4.19
45%	31969.44	9	31978.44	4.19	12.25	31981.69	4.19
50%	31969.44	12.25	31981.69	4.19	16	31985.44	4.19

Table C.45 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 150 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.19	0	31969.44	4.19
10%	31969.44	0	31969.44	4.19	0.25	31969.69	4.19
15%	31969.44	0	31969.44	4.19	0.25	31969.69	4.19
20%	31969.44	0	31969.44	4.19	0.25	31969.69	4.19
25%	31969.44	0	31969.44	4.19	0.25	31969.69	4.19
30%	31969.44	0	31969.44	4.19	0.25	31969.69	4.19
35%	31969.44	0	31969.44	4.19	0.25	31969.69	4.19
40%	31969.44	0	31969.44	4.19	1	31970.44	4.19
45%	31969.44	0	31969.44	4.19	1	31970.44	4.19
50%	31969.44	0	31969.44	4.19	1	31970.44	4.19

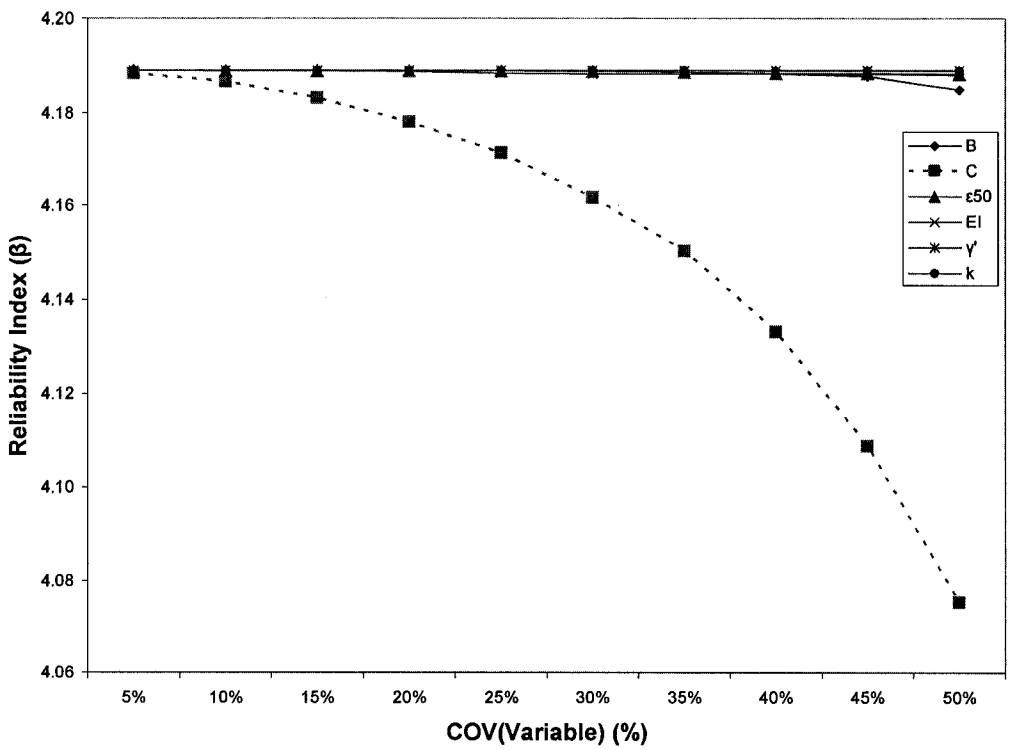

Fig. C.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single short pile (3T) at 150 kN lateral load.

For lateral load 175 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 714 \text{ kN.m}$$

Table C.46 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'B' and 'C' and applied lateral load 175 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.99	20.25	31989.69	3.99
10%	31969.44	1	31970.44	3.99	81	32050.44	3.99
15%	31969.44	1	31970.44	3.99	182.25	32151.69	3.98
20%	31969.44	2.25	31971.69	3.99	324	32293.44	3.97
25%	31969.44	6.25	31975.69	3.99	529	32498.44	3.96
30%	31969.44	16	31985.44	3.99	812.25	32781.69	3.94
35%	31969.44	36	32005.44	3.99	1190.25	33159.69	3.92
40%	31969.44	72.25	32041.69	3.99	1806.25	33775.69	3.89
45%	31969.44	225	32194.44	3.98	2809	34778.44	3.83
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table C.47 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 175 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.440	3.99	0	31969.440	3.99
10%	31969.44	0.25	31969.690	3.99	0	31969.440	3.99
15%	31969.44	1	31970.440	3.99	0	31969.440	3.99
20%	31969.44	1	31970.440	3.99	0.25	31969.690	3.99
25%	31969.44	2.25	31971.690	3.99	1	31970.440	3.99
30%	31969.44	2.25	31971.690	3.99	1	31970.440	3.99
35%	31969.44	2.25	31971.690	3.99	2.25	31971.690	3.99
40%	31969.44	4	31973.440	3.99	2.25	31971.690	3.99
45%	31969.44	2.25	31971.690	3.99	2.25	31971.690	3.99
50%	31969.44	2.25	31971.690	3.99	2.25	31971.690	3.99

Table C.48 Reliability Index connected to M_{Max} for free head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 175 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.99	0	31969.44	3.99
10%	31969.44	0	31969.44	3.99	0	31969.44	3.99
15%	31969.44	0	31969.44	3.99	0	31969.44	3.99
20%	31969.44	0	31969.44	3.99	0	31969.44	3.99
25%	31969.44	0	31969.44	3.99	0	31969.44	3.99
30%	31969.44	0	31969.44	3.99	0	31969.44	3.99
35%	31969.44	0	31969.44	3.99	0	31969.44	3.99
40%	31969.44	0	31969.44	3.99	0	31969.44	3.99
45%	31969.44	0	31969.44	3.99	0	31969.44	3.99
50%	31969.44	0	31969.44	3.99	0.25	31969.69	3.99

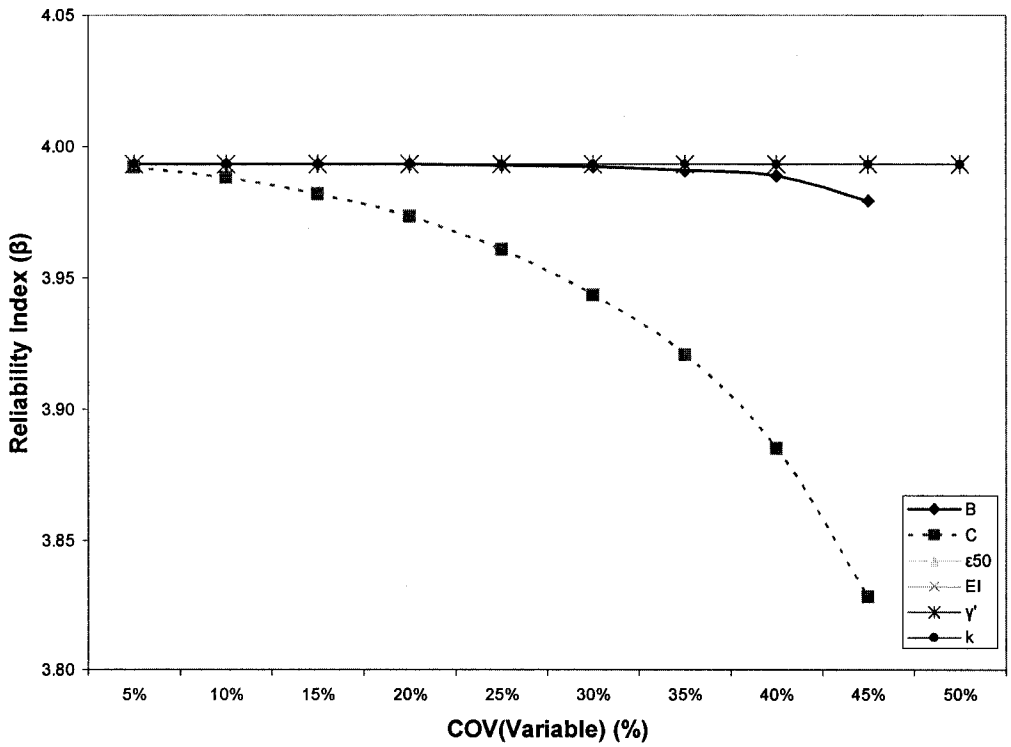

Fig. C.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single short pile (3T) at 175 kN lateral load.

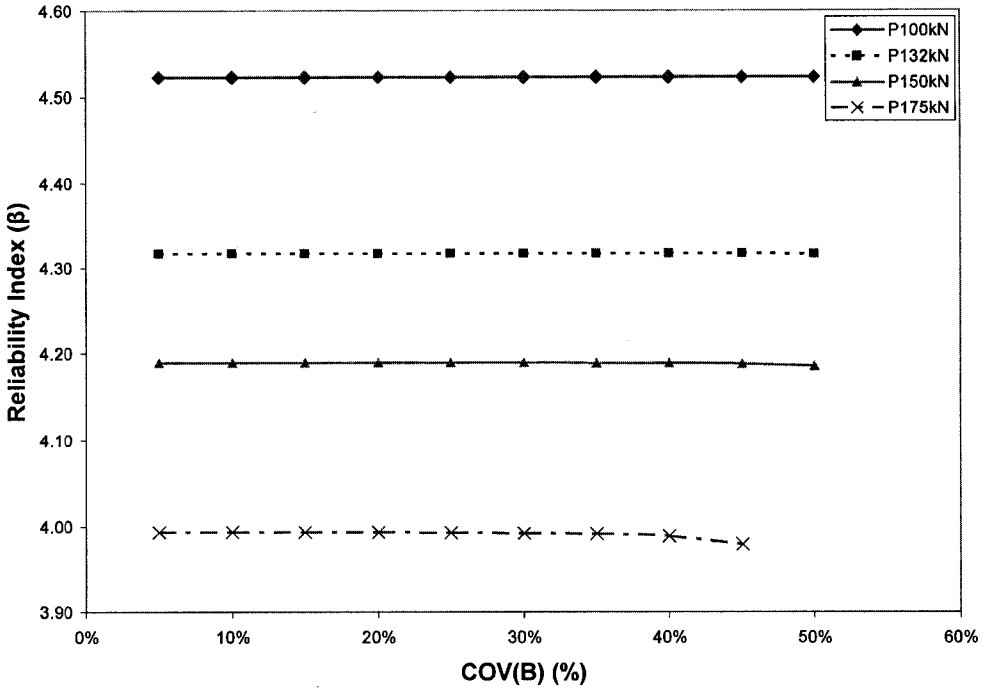

Fig. C.27 Reliability Index related to M_{Max} for free head short pile with varying 'B'.

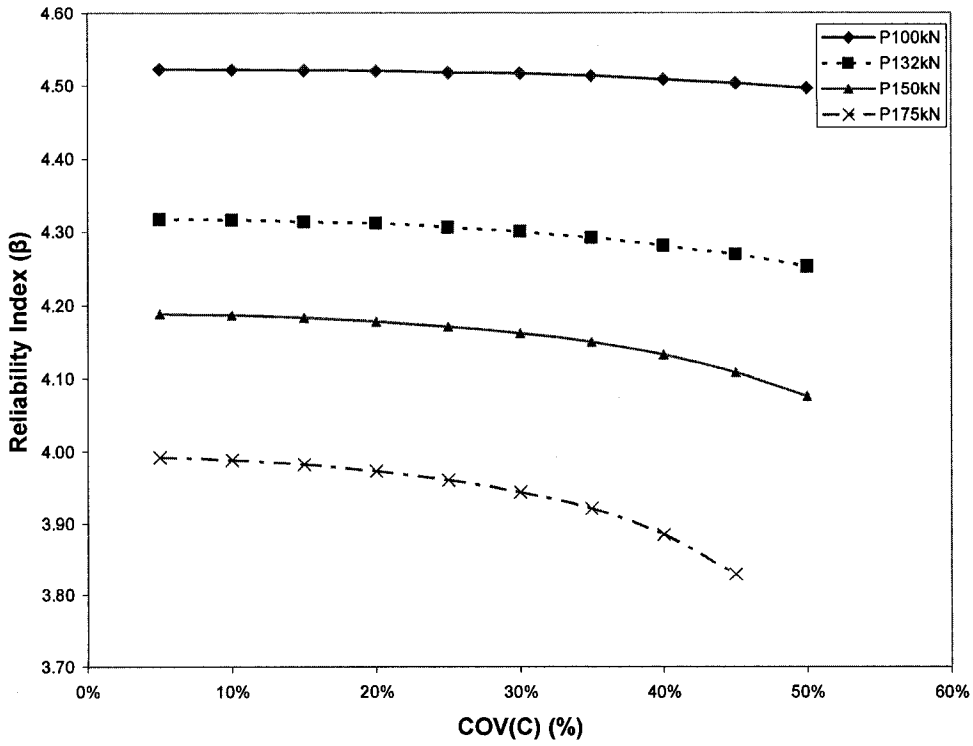

Fig. C.28 Reliability Index related to M_{Max} for free head short pile with varying 'C'.

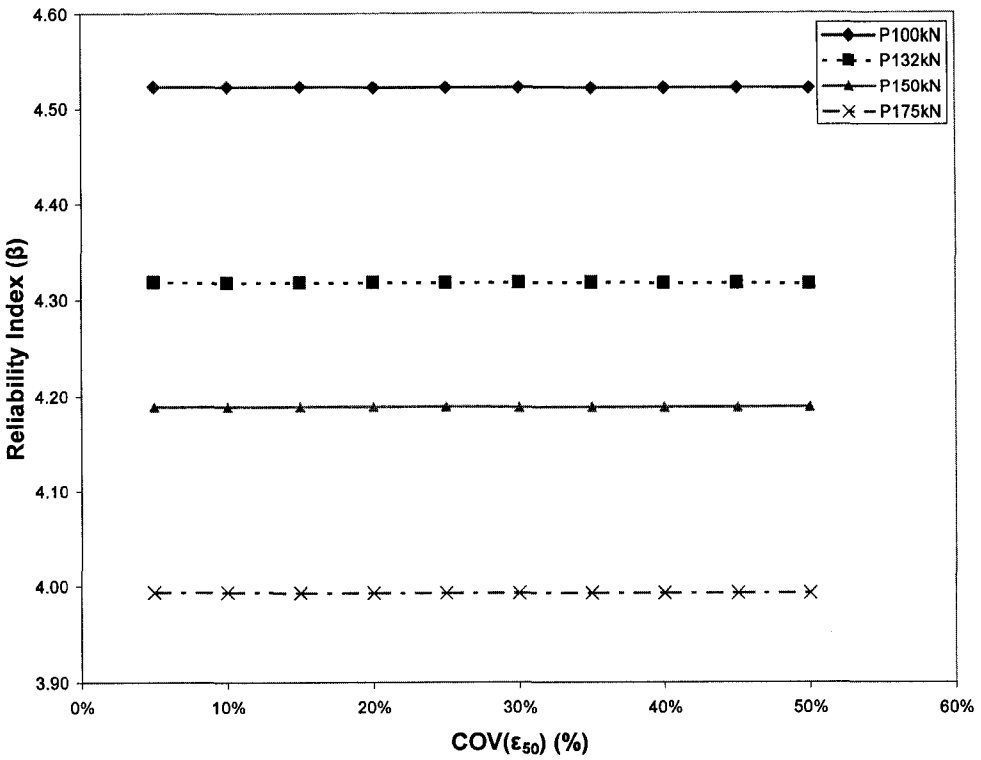

Fig.C.29 Reliability Index related to M_{Max} for free head short pile with varying 'ε_{50}'.

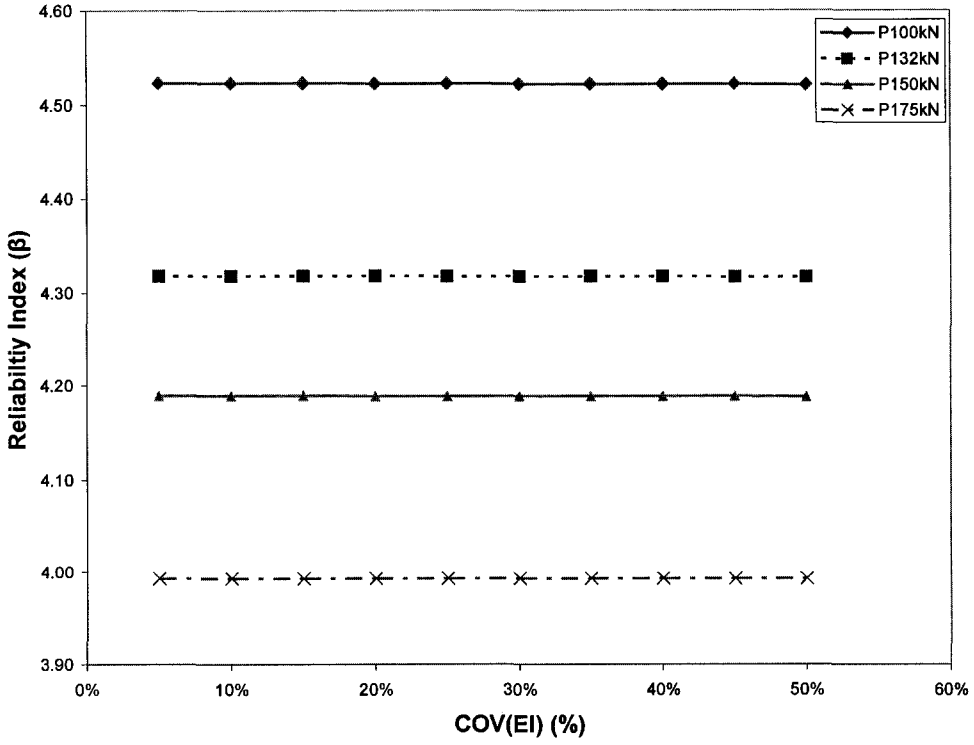

Fig. C.30 Reliability Index related to M_{Max} for free head short pile with varying 'EI'.

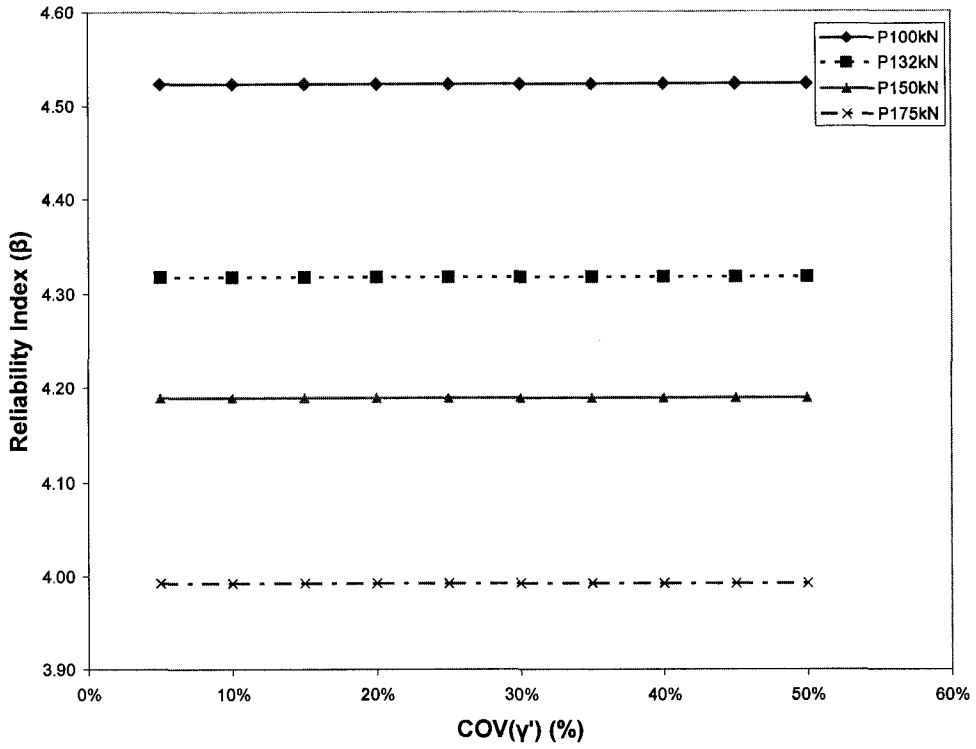

Fig. C.31 Reliability Index related to M_{Max} for free head short pile with varying 'γ'.

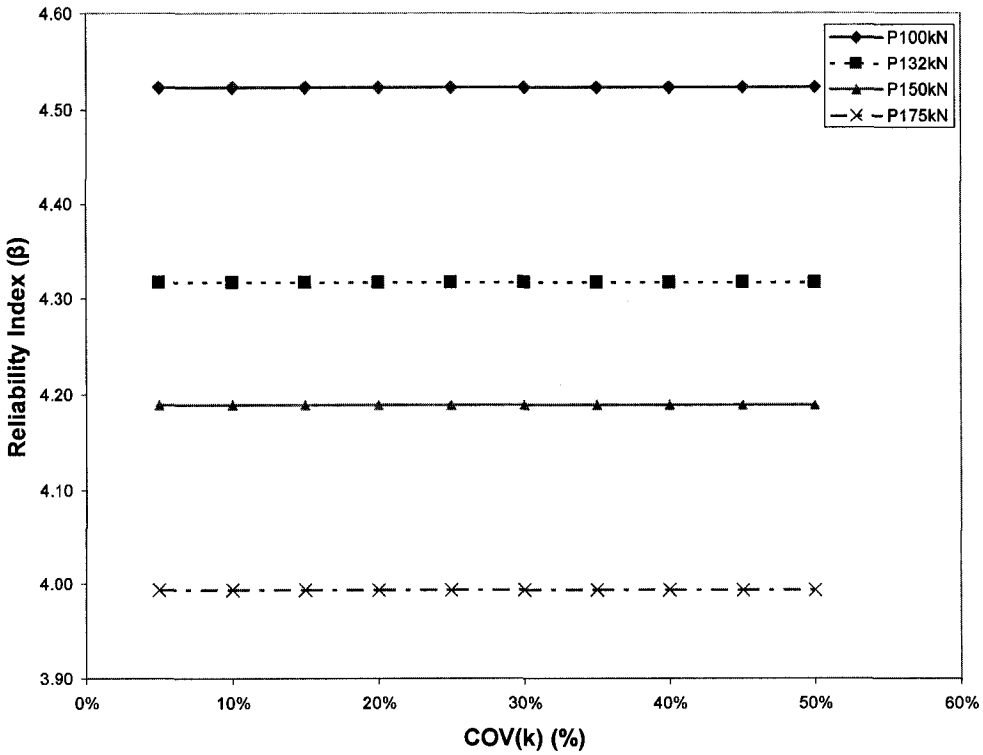

Fig. C.32 Reliability Index related to M_{Max} for free head short pile with varying 'k'.

APPENDIX D

LATERALLY LOADED FREE HEAD SINGLE LONG PILE (10T)

D.1.1 Probabilistic modeling of laterally loaded free head single long pile (10T) with 'B' as varying random design variable.

Table D.1. Values of Y_{Top} for free head single long pile (10T) with varying 'B' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	Ytop current (m)	Ytop current (m)	Ytop current (m)	Ytop current (m)
50%	0.064516	0.254	0.00316	0.00552	0.00774	Failed
45%	0.05225796	0.2794	0.00308	0.00518	0.00699	0.0114
40%	0.04129024	0.3048	0.00302	0.00493	0.00661	0.00986
35%	0.03161284	0.3302	0.00297	0.00475	0.00631	0.00914
30%	0.02322576	0.3556	0.00295	0.00469	0.00614	0.00866
25%	0.016129	0.381	0.00293	0.00465	0.00597	0.00831
20%	0.01032256	0.4064	0.00292	0.00461	0.00589	0.00811
15%	0.00580644	0.4318	0.00291	0.00459	0.00576	0.00797
10%	0.00258064	0.4572	0.00291	0.00459	0.00573	0.00781
5%	0.00064516	0.4826	0.0029	0.00457	0.00562	0.00773
0%	0	0.508	0.00291	0.00456	0.00561	0.00767
5%	0.00064516	0.5334	0.00291	0.00456	0.00561	0.00763
10%	0.00258064	0.5588	0.00291	0.00455	0.0056	0.00759
15%	0.00580644	0.5842	0.00292	0.00455	0.0056	0.00756
20%	0.01032256	0.6096	0.00292	0.00455	0.0056	0.00753
25%	0.016129	0.635	0.00292	0.00455	0.0056	0.00746
30%	0.02322576	0.6604	0.00293	0.00455	0.00563	0.00744
35%	0.03161284	0.6858	0.00293	0.00455	0.00562	0.00742
40%	0.04129024	0.7112	0.00293	0.00455	0.00562	0.0074
45%	0.05225796	0.7366	0.00293	0.00455	0.00561	0.00739
50%	0.064516	0.762	0.00294	0.00454	0.00561	0.00737

Table D.2. Values of M_{Max} for free head single long pile (10T) with varying 'B' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	Mmax current (kN-m)	Mmax current (kN-m)	Mmax current (kN-m)	Mmax current (kN-m)
50%	0.064516	0.254	86.2	129	160	Failed
45%	0.052258	0.2794	86	127	155	205
40%	0.0412902	0.3048	85.9	126	152	197
35%	0.0316128	0.3302	86.3	125	150	192
30%	0.0232258	0.3556	86.6	125	150	189
25%	0.016129	0.381	86.9	125	149	187
20%	0.0103226	0.4064	87.1	125	149	185
15%	0.0058064	0.4318	87.3	125	148	185
10%	0.0025806	0.4572	87.5	125	148	184
5%	0.0006452	0.4826	87.7	125	148	183
0%	0	0.508	87.8	125	148	183
5%	0.0006452	0.5334	87.8	125	148	183
10%	0.0025806	0.5588	87.9	125	148	183
15%	0.0058064	0.5842	87.8	125	147	182
20%	0.0103226	0.6096	87.7	124	147	182
25%	0.016129	0.635	87.7	124	147	182
30%	0.0232258	0.6604	87.5	124	146	181
35%	0.0316128	0.6858	87.4	124	146	181
40%	0.0412902	0.7112	87.2	123	146	180
45%	0.052258	0.7366	87.1	123	145	180
50%	0.064516	0.762	86.9	123	145	179

Table D.3(a) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'B' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.0006452	2.5E-11	0.166%	1.00E-10	0.211%
10%	0.0025806	0	0.000%	6.25E-10	0.527%
15%	0.0058064	2.5E-11	0.166%	1.60E-09	0.844%
20%	0.0103226	2.5E-11	0.166%	3.02E-09	1.160%
25%	0.016129	2.5E-11	0.166%	8.10E-09	1.899%
30%	0.0232258	2.25E-10	0.497%	1.82E-08	2.848%
35%	0.0316128	9E-10	0.993%	3.42E-08	3.903%
40%	0.0412902	9E-10	0.993%	7.56E-08	5.802%
45%	0.052258	4.225E-09	2.152%	1.60E-07	8.439%
50%	0.064516	1.21E-08	3.642%	3.14E-07	11.814%

Table D.3(b) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'B' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.0006452	6.25E-10	0.420%	3.60E-09	0.753%
10%	0.0025806	3.60E-09	1.008%	1.96E-08	1.757%
15%	0.0058064	9.03E-09	1.597%	4.62E-08	2.698%
20%	0.0103226	1.69E-08	2.185%	9.00E-08	3.764%
25%	0.016129	4.00E-08	3.361%	1.94E-07	5.521%
30%	0.0232258	8.12E-08	4.790%	4.29E-07	8.218%
35%	0.0316128	1.44E-07	6.387%	7.40E-07	10.790%
40%	0.0412902	2.97E-07	9.160%	1.50E-06	15.370%
45%	0.052258	6.01E-07	13.025%	3.37E-06	23.024%
50%	0.064516	1.27E-06	18.908%	Failed	Failed

Table D.4(a) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'B' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	0.0006452	0.0025	0.057%	0	0.000%
10%	0.0025806	0.04	0.228%	0	0.000%
15%	0.0058064	0.0625	0.285%	0	0.000%
20%	0.0103226	0.09	0.342%	0.25	0.400%
25%	0.016129	0.16	0.456%	0.25	0.400%
30%	0.0232258	0.2025	0.513%	0.25	0.400%
35%	0.0316128	0.3025	0.626%	0.25	0.400%
40%	0.0412902	0.4225	0.740%	2.25	1.200%
45%	0.052258	0.3025	0.626%	4	1.600%
50%	0.064516	0.1225	0.399%	9	2.400%

Table D.4(b) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'B' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	0.0006452	0	0.000%	0	0.000%
10%	0.0025806	0	0.000%	0.25	0.273%
15%	0.0058064	0.25	0.338%	2.25	0.820%
20%	0.0103226	1	0.676%	2.25	0.820%
25%	0.016129	1	0.676%	6.25	1.366%
30%	0.0232258	4	1.351%	16	2.186%
35%	0.0316128	4	1.351%	30.25	3.005%
40%	0.0412902	9	2.027%	72.25	4.645%
45%	0.052258	25	3.378%	156.25	6.831%
50%	0.064516	56.25	5.068%	Failed	Failed

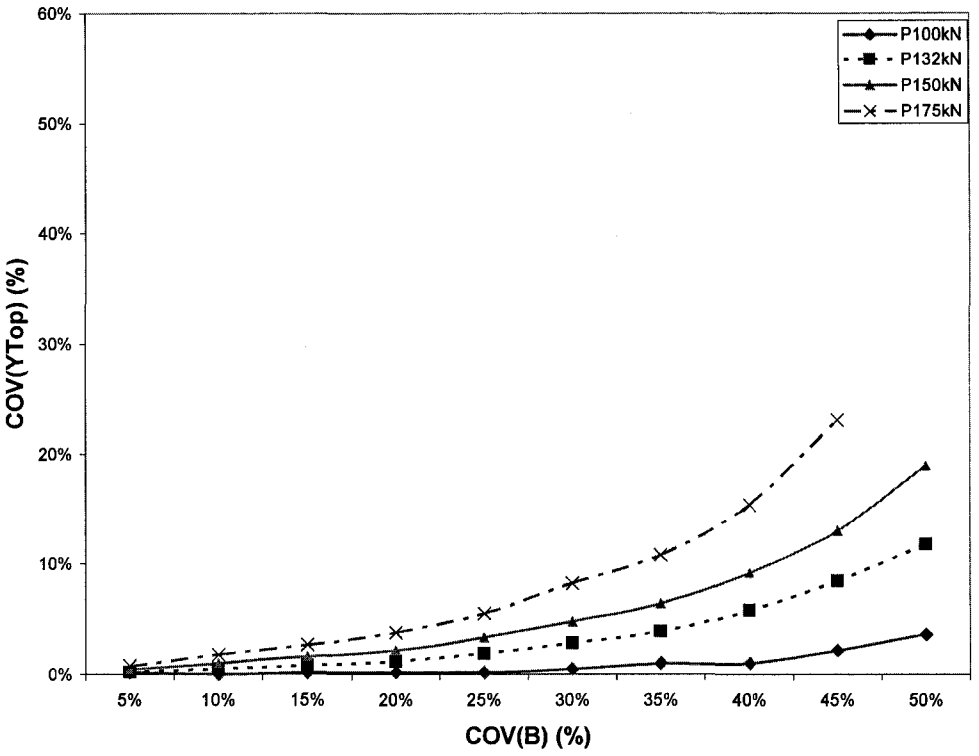

Fig. D.1 COV(Y_{Top}) for varying COV(B) in free head long pile (10T).

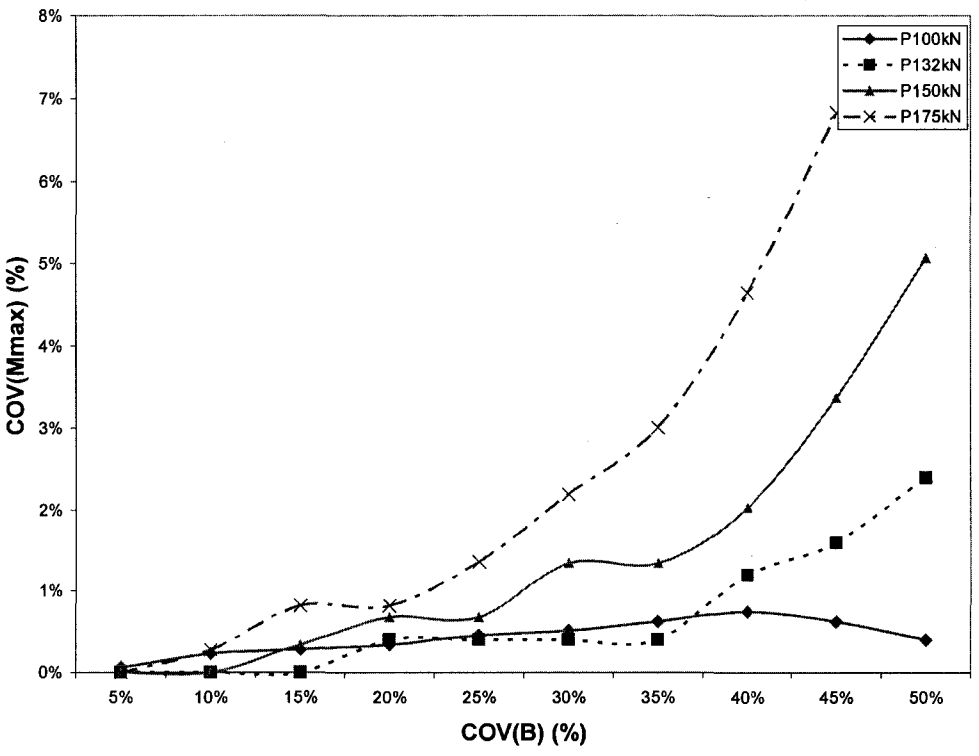

Fig. D.2 COV(M_{Max}) for varying COV(B) in free head long pile (10T).

D.1.2 Probabilistic modeling of laterally loaded free head single long pile (10T) with 'C' as varying random design variable.

Table D.5. Values of Y_{Top} for free head single long pile (10T) with varying 'C' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50.00%	1406.25	37.5	0.00634	0.0108	0.0148	0.0248
45.00%	1139.0625	41.25	0.00567	0.00946	0.0126	0.0194
40.00%	900	45	0.00515	0.00861	0.0111	0.0163
35.00%	689.0625	48.75	0.00472	0.00786	0.00999	0.0142
30.00%	506.25	52.5	0.00436	0.00715	0.00918	0.0126
25.00%	351.5625	56.25	0.00406	0.0066	0.00843	0.0114
20.00%	225	60	0.00379	0.00613	0.0078	0.0106
15.00%	126.5625	63.75	0.00356	0.00567	0.0072	0.00979
10.00%	56.25	67.5	0.00336	0.00532	0.00672	0.00913
5.00%	14.0625	71.25	0.00318	0.00501	0.00631	0.0085
0.00%	0	75	0.00302	0.00474	0.00595	0.00797
5.00%	14.0625	78.75	0.00288	0.00449	0.00563	0.00751
10.00%	56.25	82.5	0.00275	0.00428	0.00534	0.0071
15.00%	126.5625	86.25	0.00264	0.00408	0.00508	0.00673
20.00%	225	90	0.00254	0.00391	0.00485	0.0064
25.00%	351.5625	93.75	0.00245	0.00374	0.00464	0.00611
30.00%	506.25	97.5	0.00237	0.0036	0.00445	0.00584
35.00%	689.0625	101.25	0.0023	0.00347	0.00428	0.0056
40.00%	900	105	0.00223	0.0034	0.00413	0.00538
45.00%	1139.0625	108.75	0.00214	0.00329	0.00399	0.00518
50.00%	1406.25	112.5	0.00211	0.00319	0.00386	0.00499

Table D.6. Values of M_{Max} for free head single long pile (10T) with varying 'C' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50.00%	1406.25	37.5	114	168	207	284
45.00%	1139.0625	41.25	109	160	195	257
40.00%	900	45	106	155	186	240
35.00%	689.0625	48.75	102	150	179	228
30.00%	506.25	52.5	99.4	145	174	217
25.00%	351.5625	56.25	97.1	140	168	210
20.00%	225	60	95.1	136	163	204
15.00%	126.5625	63.75	93.1	133	158	199
10.00%	56.25	67.5	91.2	130	154	193
5.00%	14.0625	71.25	89.5	127	151	188
0.00%	0	75	87.8	125	148	183
5.00%	14.0625	78.75	86.2	122	145	179
10.00%	56.25	82.5	84.6	120	142	176
15.00%	126.5625	86.25	83	118	140	173
20.00%	225	90	81.8	116	137	170
25.00%	351.5625	93.75	80.7	114	135	167
30.00%	506.25	97.5	79.6	112	133	164
35.00%	689.0625	101.25	78.5	110	131	161
40.00%	900	105	77.5	109	129	159
45.00%	1139.0625	108.75	75.7	108	126	156
50.00%	1406.25	112.5	75.2	107	125	154

Table D.7(a) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'C' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	2.25E-08	4.967%	6.76E-08	5.485%
10.00%	5.63E+01	9.30E-08	10.099%	2.70E-07	10.970%
15.00%	1.27E+02	2.12E-07	15.232%	6.32E-07	16.772%
20.00%	2.25E+02	3.91E-07	20.695%	1.23E-06	23.418%
25.00%	3.52E+02	6.48E-07	26.656%	2.04E-06	30.169%
30.00%	5.06E+02	9.90E-07	32.947%	3.15E-06	37.447%
35.00%	6.89E+02	1.46E-06	40.066%	4.82E-06	46.308%
40.00%	9.00E+02	2.13E-06	48.344%	6.79E-06	54.958%
45.00%	1.14E+03	3.12E-06	58.444%	9.52E-06	65.084%
50.00%	1.41E+03	4.47E-06	70.033%	1.45E-05	80.274%

Table D.7(b) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'C' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	1.16E-07	5.714%	2.45E-07	6.211%
10.00%	5.63E+01	4.76E-07	11.597%	1.03E-06	12.735%
15.00%	1.27E+02	1.12E-06	17.815%	2.34E-06	19.197%
20.00%	2.25E+02	2.18E-06	24.790%	4.41E-06	26.349%
25.00%	3.52E+02	3.59E-06	31.849%	7.00E-06	33.187%
30.00%	5.06E+02	5.59E-06	39.748%	1.14E-05	42.409%
35.00%	6.89E+02	8.15E-06	47.983%	1.85E-05	53.952%
40.00%	9.00E+02	1.21E-05	58.571%	2.98E-05	68.507%
45.00%	1.14E+03	1.85E-05	72.353%	5.06E-05	89.210%
50.00%	1.41E+03	2.99E-05	91.933%	9.81E-05	124.279%

Table D.8(a) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'C' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	14.0625	2.7225	1.879%	6.25	2.000%
10.00%	56.25	10.89	3.759%	25	4.000%
15.00%	126.5625	25.5025	5.752%	56.25	6.000%
20.00%	225	44.2225	7.574%	100	8.000%
25.00%	351.5625	67.24	9.339%	169	10.400%
30.00%	506.25	98.01	11.276%	272.25	13.200%
35.00%	689.0625	138.0625	13.383%	400	16.000%
40.00%	900	203.0625	16.230%	529	18.400%
45.00%	1139.0625	277.2225	18.964%	676	20.800%
50.00%	1406.25	376.36	22.096%	930.25	24.400%

Table D.8(b) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'C' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	14.0625	9	2.027%	20.25	2.459%
10.00%	56.25	36	4.054%	72.25	4.645%
15.00%	126.5625	81	6.081%	169	7.104%
20.00%	225	169	8.784%	289	9.290%
25.00%	351.5625	272.25	11.149%	462.25	11.749%
30.00%	506.25	420.25	13.851%	702.25	14.481%
35.00%	689.0625	576	16.216%	1122.25	18.306%
40.00%	900	812.25	19.257%	1640.25	22.131%
45.00%	1139.0625	1190.25	23.311%	2550.25	27.596%
50.00%	1406.25	1681	27.703%	4225	35.519%

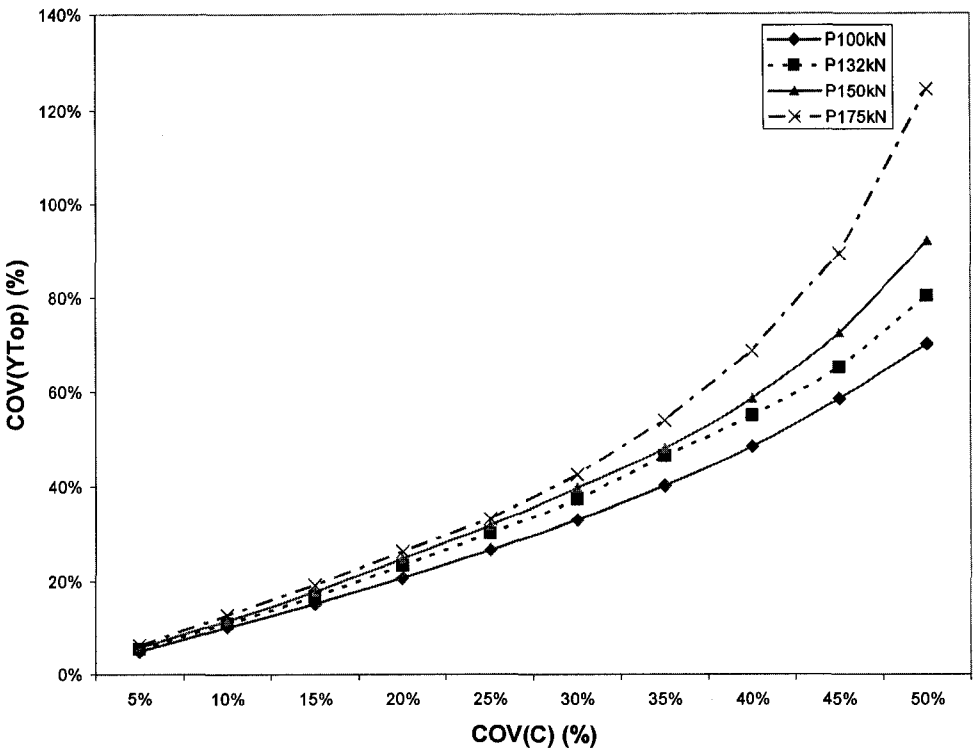

Fig. D.3 COV(Y_{Top}) for varying COV(C) in free head long pile (10T).

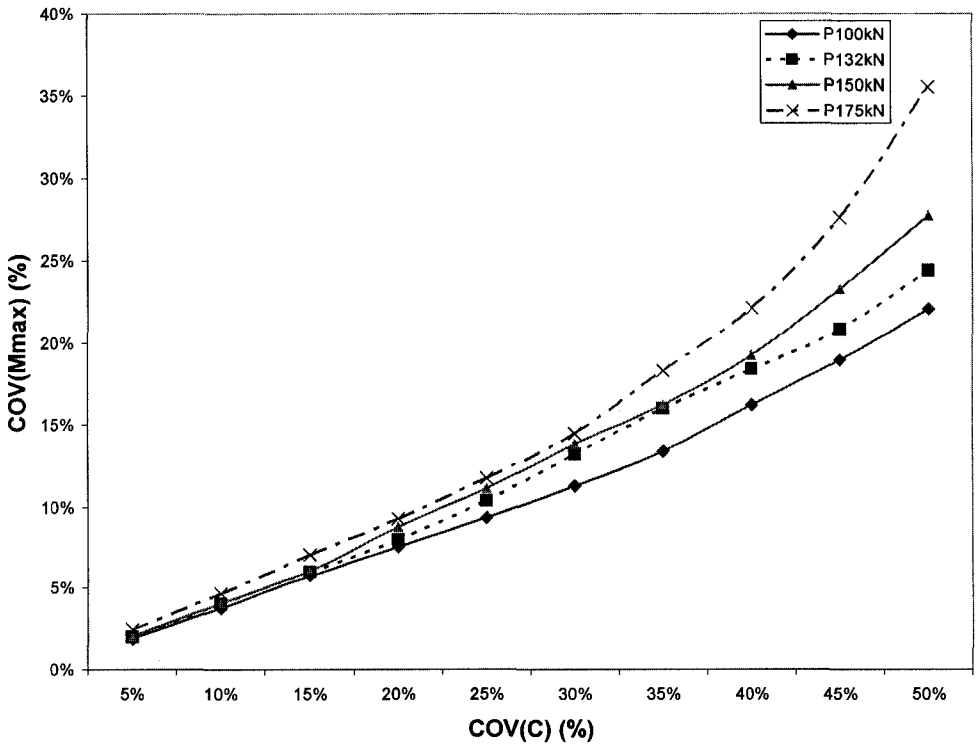

Fig. D.4 COV(M_{Max}) for varying COV(C) in free head long pile (10T).

D.1.3 Probabilistic modeling of laterally loaded free head single long pile (10T) with 'ε_{50}' as varying random design variable.

Table D.9. Values of Y_{Top} for free head single long pile (10T) with varying 'ε_{50}' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	0.00001225	0.0035	0.0024	0.00385	0.00497	0.00696
45%	9.9225E-06	0.00385	0.00245	0.00393	0.00506	0.00702
40%	0.00000784	0.0042	0.00251	0.00402	0.00516	0.00711
35%	6.0025E-06	0.00455	0.00258	0.00411	0.00526	0.0072
30%	0.00000441	0.0049	0.00264	0.0042	0.00536	0.00731
25%	3.0625E-06	0.00525	0.00271	0.00429	0.00546	0.00742
20%	0.00000196	0.0056	0.00277	0.00438	0.00555	0.00753
15%	1.1025E-06	0.00595	0.00283	0.00447	0.00565	0.00764
10%	0.00000049	0.0063	0.0029	0.00456	0.00575	0.00776
5%	1.225E-07	0.00665	0.00296	0.00465	0.00585	0.00787
0%	0	0.007	0.00302	0.00474	0.00595	0.00797
5%	1.225E-07	0.00735	0.00308	0.00482	0.00604	0.00808
10%	0.00000049	0.0077	0.00314	0.00491	0.00614	0.00818
15%	1.1025E-06	0.00805	0.0032	0.00499	0.00624	0.00829
20%	0.00000196	0.0084	0.00326	0.00507	0.00633	0.0084
25%	3.0625E-06	0.00875	0.00332	0.0052	0.00642	0.0085
30%	0.00000441	0.0091	0.00337	0.00528	0.00652	0.00861
35%	6.0025E-06	0.00945	0.00343	0.00536	0.00661	0.00871
40%	0.00000784	0.0098	0.00348	0.00544	0.0067	0.00882
45%	9.9225E-06	0.01015	0.00353	0.00551	0.00678	0.00892
50%	0.00001225	0.0105	0.00359	0.00559	0.00687	0.00902

Table D.10. Values of M_{Max} for free head single long pile (10T) with varying 'ε_{50}' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	0.00001225	0.0035	81.7	120	146	185
45%	9.9225E-06	0.00385	82.3	120	146	184
40%	0.00000784	0.0042	82.9	121	146	183
35%	6.0025E-06	0.00455	83.4	121	146	183
30%	0.00000441	0.0049	83.9	122	146	183
25%	3.0625E-06	0.00525	84.6	122	146	183
20%	0.00000196	0.0056	85.3	123	147	183
15%	1.1025E-06	0.00595	86	123	147	183
10%	0.00000049	0.0063	86.6	124	147	183
5%	1.225E-07	0.00665	87.2	124	148	183
0%	0	0.007	87.8	125	148	183
5%	1.225E-07	0.00735	88.3	125	148	183
10%	0.00000049	0.0077	88.8	126	149	184
15%	1.1025E-06	0.00805	89.3	126	149	184
20%	0.00000196	0.0084	89.8	127	149	184
25%	3.0625E-06	0.00875	90.2	127	150	185
30%	0.00000441	0.0091	90.6	128	150	185
35%	6.0025E-06	0.00945	91.1	128	150	186
40%	0.00000784	0.0098	91.5	129	151	186
45%	9.9225E-06	0.01015	91.8	129	151	186
50%	0.00001225	0.0105	92.2	129	152	187

Table D.11(a) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'ε_{50}' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	3.60E-09	1.987%	7.22E-09	1.793%
10%	4.90E-07	1.44E-08	3.974%	3.06E-08	3.692%
15%	1.10E-06	3.42E-08	6.126%	6.76E-08	5.485%
20%	1.96E-06	6.00E-08	8.113%	1.19E-07	7.278%
25%	3.06E-06	9.30E-08	10.099%	2.07E-07	9.599%
30%	4.41E-06	1.33E-07	12.086%	2.92E-07	11.392%
35%	6.00E-06	1.81E-07	14.073%	3.91E-07	13.186%
40%	7.84E-06	2.35E-07	16.060%	5.04E-07	14.979%
45%	9.92E-06	2.92E-07	17.881%	6.24E-07	16.667%
50%	1.23E-05	3.54E-07	19.702%	7.57E-07	18.354%

Table D.11(b) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'ε_{50}' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	9.02E-09	1.597%	1.10E-08	1.317%
10%	4.90E-07	3.80E-08	3.277%	4.41E-08	2.635%
15%	1.10E-06	8.70E-08	4.958%	1.06E-07	4.078%
20%	1.96E-06	1.52E-07	6.555%	1.89E-07	5.458%
25%	3.06E-06	2.30E-07	8.067%	2.92E-07	6.775%
30%	4.41E-06	3.36E-07	9.748%	4.23E-07	8.156%
35%	6.00E-06	4.56E-07	11.345%	5.70E-07	9.473%
40%	7.84E-06	5.93E-07	12.941%	7.31E-07	10.728%
45%	9.92E-06	7.40E-07	14.454%	9.03E-07	11.920%
50%	1.23E-05	9.03E-07	15.966%	1.06E-06	12.923%

Table D.12(a) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'ε_{50}' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) (kN-m)^2	COV(M_{Max}) (%)	VAR(M_{Max}) (kN-m)^2	COV(M_{Max}) (%)
5%	1.23E-07	0.3025	0.626%	0.25	0.400%
10%	4.90E-07	1.21	1.253%	1	0.800%
15%	1.10E-06	2.7225	1.879%	2.25	1.200%
20%	1.96E-06	5.0625	2.563%	4	1.600%
25%	3.06E-06	7.84	3.189%	6.25	2.000%
30%	4.41E-06	11.2225	3.815%	9	2.400%
35%	6.00E-06	14.8225	4.385%	12.25	2.800%
40%	7.84E-06	18.49	4.897%	16	3.200%
45%	9.92E-06	22.5625	5.410%	20.25	3.600%
50%	1.23E-05	27.5625	5.979%	20.25	3.600%

Table D.12(b) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'ε_{50}' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) (kN-m)^2	COV(M_{Max}) (%)	VAR(M_{Max}) (kN-m)^2	COV(M_{Max}) (%)
5%	1.23E-07	0	0.000%	0	0.000%
10%	4.90E-07	1	0.676%	0.25	0.273%
15%	1.10E-06	1	0.676%	0.25	0.273%
20%	1.96E-06	1	0.676%	0.25	0.273%
25%	3.06E-06	4	1.351%	1	0.546%
30%	4.41E-06	4	1.351%	1	0.546%
35%	6.00E-06	4	1.351%	2.25	0.820%
40%	7.84E-06	6.25	1.689%	2.25	0.820%
45%	9.92E-06	6.25	1.689%	1	0.546%
50%	1.23E-05	9	2.027%	1	0.546%

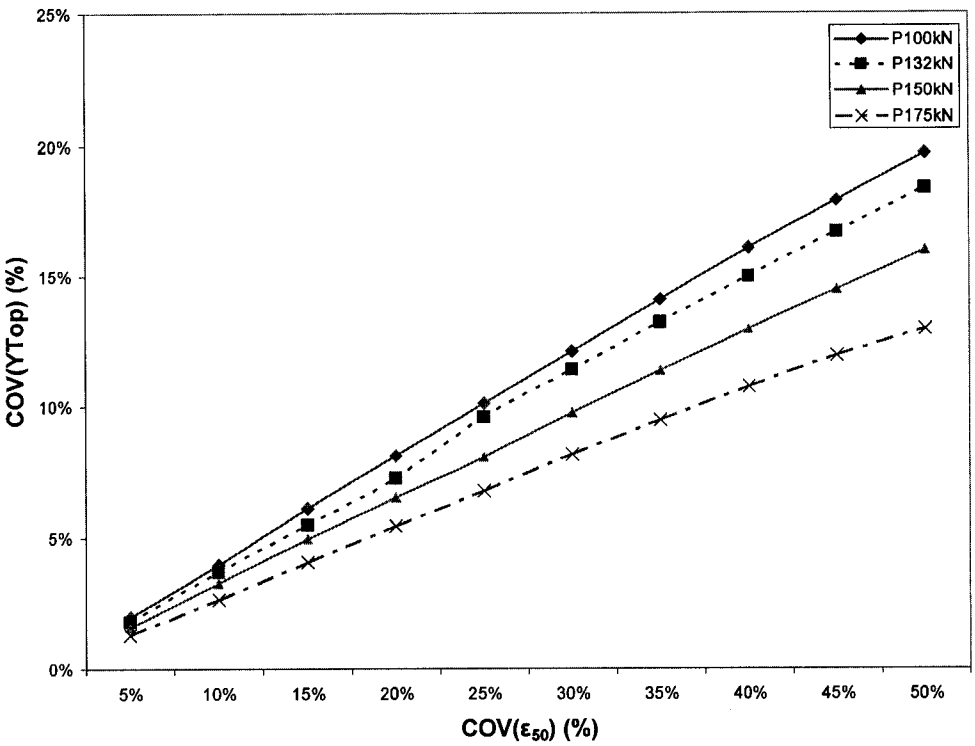

Fig. D.5 COV(Y_{Top}) for varying COV(ε_{50}) in free head long pile (10T).

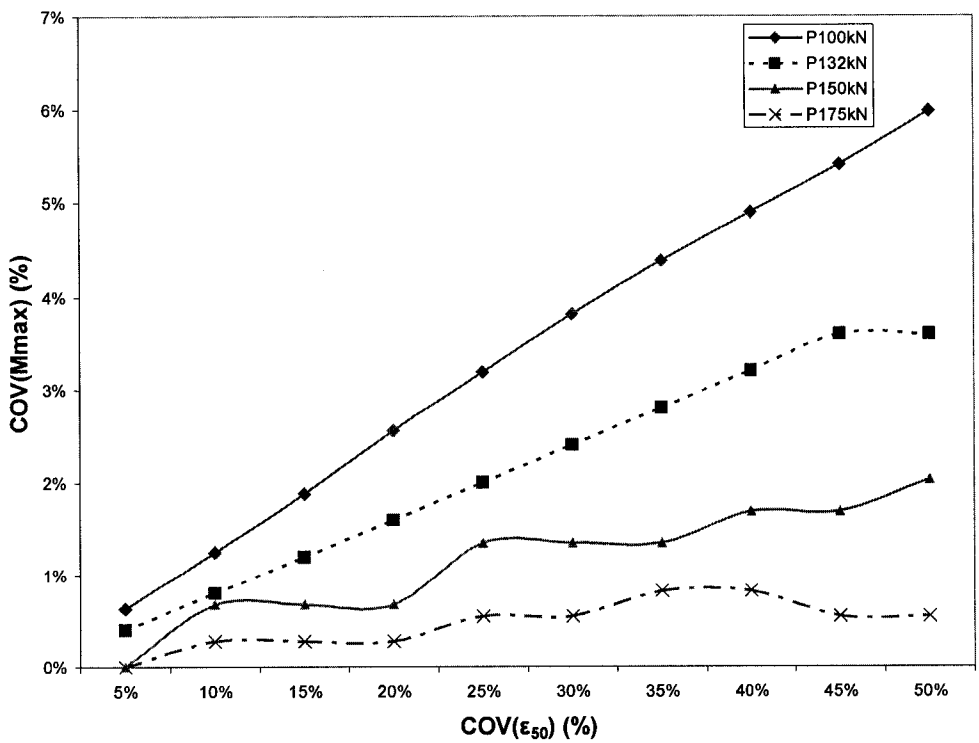

Fig. D.6 COV(M_{Max}) for varying COV(ε_{50}) in free head long pile (10T).

D.1.4 Probabilistic modeling of laterally loaded free head single long pile (10T) with 'EI' as varying random design variable.

Table D.13 Values of Y_{Top} for free head single long pile (10T) with varying 'EI' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(kN.m^2)$	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	3.03E+09	5.50E+04	0.00427	0.00696	0.00898	0.0125
45%	2.45E+09	6.05E+04	0.00414	0.00673	0.00866	0.012
40%	1.94E+09	6.60E+04	0.00403	0.00652	0.00838	0.0116
35%	1.48E+09	7.15E+04	0.00394	0.00635	0.00813	0.0112
30%	1.09E+09	7.70E+04	0.00337	0.00538	0.00675	0.00916
25%	7.56E+08	8.25E+04	0.0033	0.00526	0.00659	0.00893
20%	4.84E+08	8.80E+04	0.00324	0.00515	0.00644	0.00871
15%	2.72E+08	9.35E+04	0.00322	0.00505	0.00636	0.00852
10%	1.21E+08	9.90E+04	0.00317	0.00496	0.00624	0.00834
5%	3.03E+07	1.05E+05	0.00312	0.00488	0.00613	0.00817
0%	0.00E+00	1.10E+05	0.00302	0.00474	0.00595	0.00797
5%	3.03E+07	1.16E+05	0.00272	0.00422	0.00526	0.00698
10%	1.21E+08	1.21E+05	0.00269	0.00416	0.00518	0.00687
15%	2.72E+08	1.27E+05	0.00265	0.00411	0.00511	0.00676
20%	4.84E+08	1.32E+05	0.00262	0.00405	0.00504	0.00667
25%	7.56E+08	1.38E+05	0.00259	0.004	0.00498	0.00657
30%	1.09E+09	1.43E+05	0.00256	0.00396	0.00492	0.00649
35%	1.48E+09	1.49E+05	0.00254	0.00391	0.00486	0.00641
40%	1.94E+09	1.54E+05	0.0023	0.00357	0.00437	0.00572
45%	2.45E+09	1.60E+05	0.00228	0.00354	0.00433	0.00566
50%	3.03E+09	1.65E+05	0.00226	0.0035	0.00428	0.0056

Table D.14. Values of M_{Max} for free head single long pile (10T) with varying 'EI' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(kN.m^2)$	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	3.03E+09	5.50E+04	83.2	121	146	183
45%	2.45E+09	6.05E+04	83.6	122	146	183
40%	1.94E+09	6.60E+04	84	122	146	183
35%	1.48E+09	7.15E+04	84.3	122	146	183
30%	1.09E+09	7.70E+04	86.7	124	147	184
25%	7.56E+08	8.25E+04	87.1	124	147	184
20%	4.84E+08	8.80E+04	87.4	124	147	184
15%	2.72E+08	9.35E+04	88	125	148	184
10%	1.21E+08	9.90E+04	88.3	125	148	184
5%	3.03E+07	1.05E+05	88.5	125	148	184
0%	0.00E+00	1.10E+05	87.8	125	148	184
5%	3.03E+07	1.16E+05	90.7	127	150	186
10%	1.21E+08	1.21E+05	90.9	127	151	187
15%	2.72E+08	1.27E+05	91.1	127	151	187
20%	4.84E+08	1.32E+05	91.3	128	151	187
25%	7.56E+08	1.38E+05	91.5	128	152	187
30%	1.09E+09	1.43E+05	91.7	128	152	187
35%	1.48E+09	1.49E+05	91.9	129	152	188
40%	1.94E+09	1.54E+05	93.6	132	155	190
45%	2.45E+09	1.60E+05	93.8	132	155	190
50%	3.03E+09	1.65E+05	93.9	132	155	190

Table D.15(a) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'EI' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	4.00E-08	6.623%	1.09E-07	6.962%
10%	1.21E+08	5.76E-08	7.947%	1.60E-07	8.439%
15%	2.72E+08	8.12E-08	9.437%	2.21E-07	9.916%
20%	4.84E+08	9.61E-08	10.265%	3.03E-07	11.603%
25%	7.56E+08	1.26E-07	11.755%	3.97E-07	13.291%
30%	1.09E+09	1.64E-07	13.411%	5.04E-07	14.979%
35%	1.48E+09	4.90E-07	23.179%	1.49E-06	25.738%
40%	1.94E+09	7.48E-07	28.642%	2.18E-06	31.118%
45%	2.45E+09	8.65E-07	30.795%	2.54E-06	33.650%
50%	3.03E+09	1.01E-06	33.278%	2.99E-06	36.498%

Table D.15(b) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'EI' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	1.89E-07	7.311%	3.54E-07	7.465%
10%	1.21E+08	2.81E-07	8.908%	5.40E-07	9.222%
15%	2.72E+08	3.91E-07	10.504%	7.74E-07	11.041%
20%	4.84E+08	4.90E-07	11.765%	1.04E-06	12.798%
25%	7.56E+08	6.48E-07	13.529%	1.39E-06	14.806%
30%	1.09E+09	8.37E-07	15.378%	1.78E-06	16.750%
35%	1.48E+09	2.67E-06	27.479%	5.74E-06	30.050%
40%	1.94E+09	4.02E-06	33.697%	8.64E-06	36.888%
45%	2.45E+09	4.69E-06	36.387%	1.00E-05	39.774%
50%	3.03E+09	5.52E-06	39.496%	1.19E-05	43.287%

Table D.16(a) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'EI' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	1.21	1.253%	1	0.800%
10%	1.21E+08	1.69	1.481%	1	0.800%
15%	2.72E+08	2.4025	1.765%	1	0.800%
20%	4.84E+08	3.8025	2.221%	4	1.600%
25%	7.56E+08	4.84	2.506%	4	1.600%
30%	1.09E+09	6.25	2.847%	4	1.600%
35%	1.48E+09	14.44	4.328%	12.25	2.800%
40%	1.94E+09	23.04	5.467%	25	4.000%
45%	2.45E+09	26.01	5.809%	25	4.000%
50%	3.03E+09	28.6225	6.093%	30.25	4.400%

Table D.16(b) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'EI' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	1	0.676%	1	0.546%
10%	1.21E+08	2.25	1.014%	2.25	0.820%
15%	2.72E+08	2.25	1.014%	2.25	0.820%
20%	4.84E+08	4	1.351%	2.25	0.820%
25%	7.56E+08	6.25	1.689%	2.25	0.820%
30%	1.09E+09	6.25	1.689%	2.25	0.820%
35%	1.48E+09	9	2.027%	6.25E+00	1.366%
40%	1.94E+09	20.25	3.041%	1.23E+01	1.913%
45%	2.45E+09	20.25	3.041%	1.23E+01	1.913%
50%	3.03E+09	20.25	3.041%	1.23E+01	1.913%

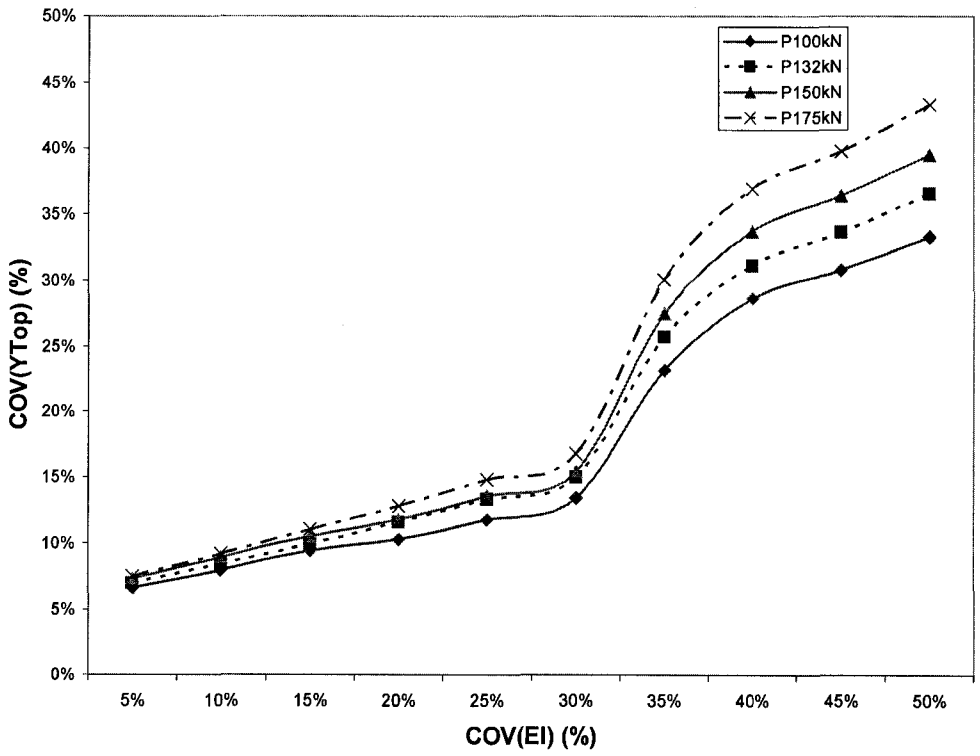

Fig. D.7 COV(Y_{Top}) for varying COV(EI) in free head long pile (10T).

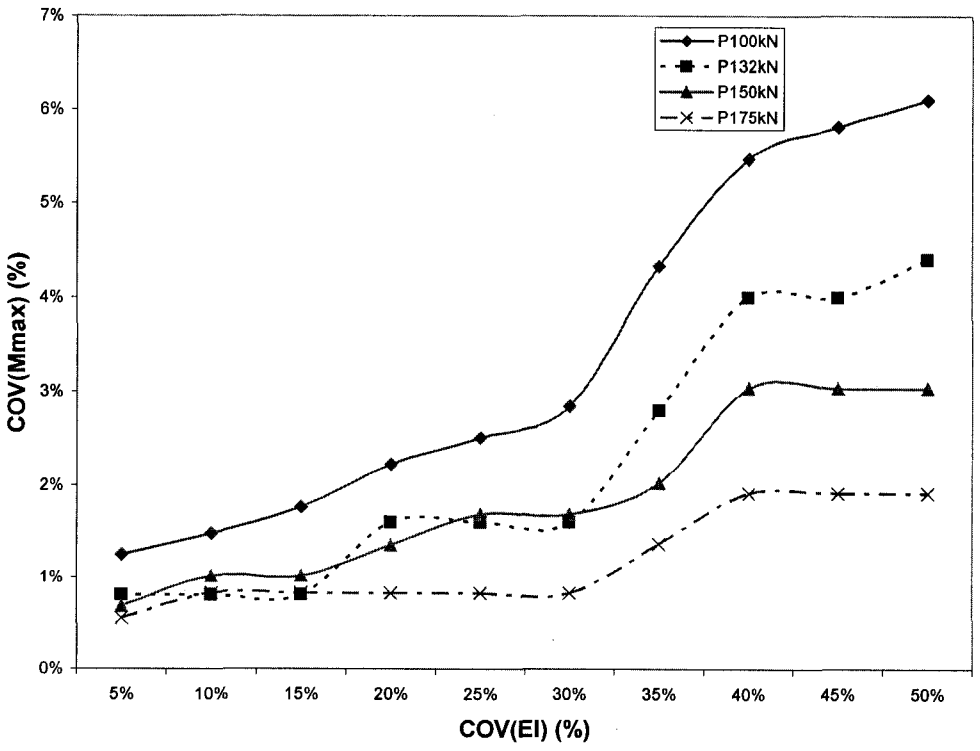

Fig. D.8 COV(M_{Max}) for varying COV(EI) in free head long pile (10T).

D.1.5 Probabilistic modeling of laterally loaded free head single long pile (10T) with 'k' as varying random design variable.

Table D.17 Values of Y_{Top} for free head single long pile (10T) with varying 'k' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	4.62E+09	68000	0.00316	0.00483	0.00602	0.00799
45%	3.75E+09	74800	0.00313	0.0048	0.006	0.00798
40%	2.96E+09	81600	0.0031	0.00478	0.00598	0.00797
35%	2.27E+09	88400	0.00307	0.00476	0.00597	0.00802
30%	1.66E+09	95200	0.00305	0.00476	0.00597	0.00801
25%	1.16E+09	102000	0.00304	0.00475	0.00596	0.008
20%	7.40E+08	108800	0.00304	0.00475	0.00596	0.00799
15%	4.16E+08	115600	0.00303	0.00474	0.00595	0.00799
10%	1.85E+08	122400	0.00303	0.00474	0.00595	0.00798
5%	4.62E+07	129200	0.00302	0.00474	0.00595	0.00798
0%	0.00E+00	136000	0.00302	0.00474	0.00595	0.00797
5%	4.62E+07	142800	0.00302	0.00474	0.00594	0.00797
10%	1.85E+08	149600	0.00302	0.00473	0.00594	0.00796
15%	4.16E+08	156400	0.00302	0.00473	0.00594	0.00796
20%	7.40E+08	163200	0.00302	0.00478	0.00594	0.00795
25%	1.16E+09	170000	0.00302	0.00478	0.00594	0.00795
30%	1.66E+09	176800	0.00301	0.00478	0.00593	0.008
35%	2.27E+09	183600	0.00301	0.00477	0.00593	0.008
40%	2.96E+09	190400	0.00301	0.00477	0.00593	0.00799
45%	3.75E+09	197200	0.00301	0.00477	0.00598	0.00798
50%	4.62E+09	204000	0.00301	0.00477	0.00598	0.00798

Table D.18. Values of M_{Max} for free head single long pile (10T) with varying 'k' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	4.62E+09	68000	85.3	124	148	183
45%	3.75E+09	74800	86.3	125	148	183
40%	2.96E+09	81600	86.8	125	148	183
35%	2.27E+09	88400	87.3	125	148	183
30%	1.66E+09	95200	87.5	125	148	183
25%	1.16E+09	102000	87.6	125	148	183
20%	7.40E+08	108800	87.7	125	148	183
15%	4.16E+08	115600	87.8	125	148	183
10%	1.85E+08	122400	87.8	125	148	183
5%	4.62E+07	129200	87.8	125	148	183
0%	0.00E+00	136000	87.8	125	148	183
5%	4.62E+07	142800	87.8	125	148	183
10%	1.85E+08	149600	87.8	125	148	183
15%	4.16E+08	156400	87.8	125	148	183
20%	7.40E+08	163200	87.8	125	148	183
25%	1.16E+09	170000	87.8	125	148	183
30%	1.66E+09	176800	87.8	125	148	183
35%	2.27E+09	183600	87.8	125	148	183
40%	2.96E+09	190400	87.8	125	148	183
45%	3.75E+09	197200	87.8	125	148	183
50%	4.62E+09	204000	87.8	125	148	183

Table D.19(a) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'k' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	2.50E-11	0.166%	2.50E-11	0.105%
15%	4.16E+08	2.50E-11	0.166%	2.50E-11	0.105%
20%	7.40E+08	1.00E-10	0.331%	2.25E-10	0.316%
25%	1.16E+09	1.00E-10	0.331%	2.25E-10	0.316%
30%	1.66E+09	4.00E-10	0.662%	1.00E-10	0.211%
35%	2.27E+09	9.00E-10	0.993%	2.50E-11	0.105%
40%	2.96E+09	2.02E-09	1.490%	2.50E-11	0.105%
45%	3.75E+09	3.60E-09	1.987%	2.25E-10	0.316%
50%	4.62E+09	5.63E-09	2.483%	9.00E-10	0.633%

Table D.19(b) Value of COV(Y_{Top}) for free head single long pile (10T) with varying 'k' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.50E-11	0.084%	2.50E-11	0.063%
10%	1.85E+08	2.50E-11	0.084%	1.00E-10	0.125%
15%	4.16E+08	2.50E-11	0.084%	2.25E-10	0.188%
20%	7.40E+08	1.00E-10	0.168%	4.00E-10	0.251%
25%	1.16E+09	1.00E-10	0.168%	6.25E-10	0.314%
30%	1.66E+09	4.00E-10	0.336%	2.50E-11	0.063%
35%	2.27E+09	4.00E-10	0.336%	1.00E-10	0.125%
40%	2.96E+09	6.25E-10	0.420%	1.00E-10	0.125%
45%	3.75E+09	1.00E-10	0.168%	0.00E+00	0.000%
50%	4.62E+09	4.00E-10	0.336%	2.50E-11	0.063%

Table D.20(a) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'k' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0	0.000%	0	0.000%
10%	1.85E+08	0	0.000%	0	0.000%
15%	4.16E+08	0	0.000%	0	0.000%
20%	7.40E+08	0.0025	0.057%	0	0.000%
25%	1.16E+09	0.01	0.114%	0	0.000%
30%	1.66E+09	0.0225	0.171%	0	0.000%
35%	2.27E+09	0.0625	0.285%	0	0.000%
40%	2.96E+09	0.25	0.569%	0	0.000%
45%	3.75E+09	0.5625	0.854%	0	0.000%
50%	4.62E+09	1.5625	1.424%	0.25	0.400%

Table D.20(b) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'k' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0	0.000%	0	0.000%
10%	1.85E+08	0	0.000%	0	0.000%
15%	4.16E+08	0	0.000%	0	0.000%
20%	7.40E+08	0	0.000%	0	0.000%
25%	1.16E+09	0	0.000%	0	0.000%
30%	1.66E+09	0	0.000%	0	0.000%
35%	2.27E+09	0	0.000%	0	0.000%
40%	2.96E+09	0	0.000%	0	0.000%
45%	3.75E+09	0	0.000%	0	0.000%
50%	4.62E+09	0	0.000%	0	0.000%

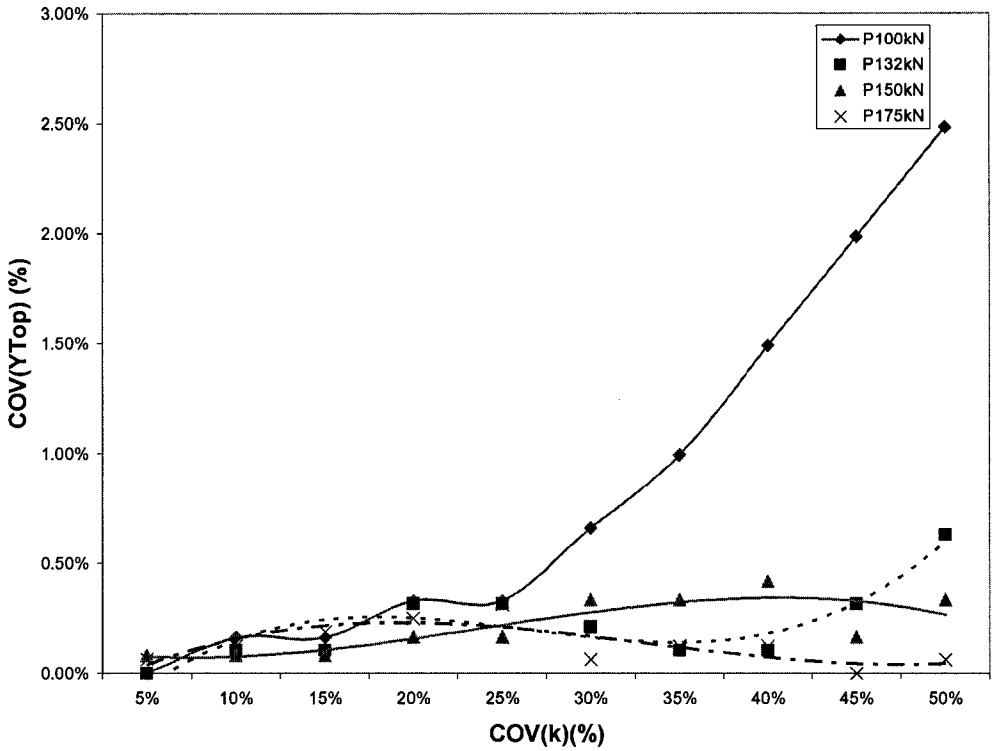

Fig. D.9 COV(Y_{Top}) for varying COV(k) in free head long pile (10T).

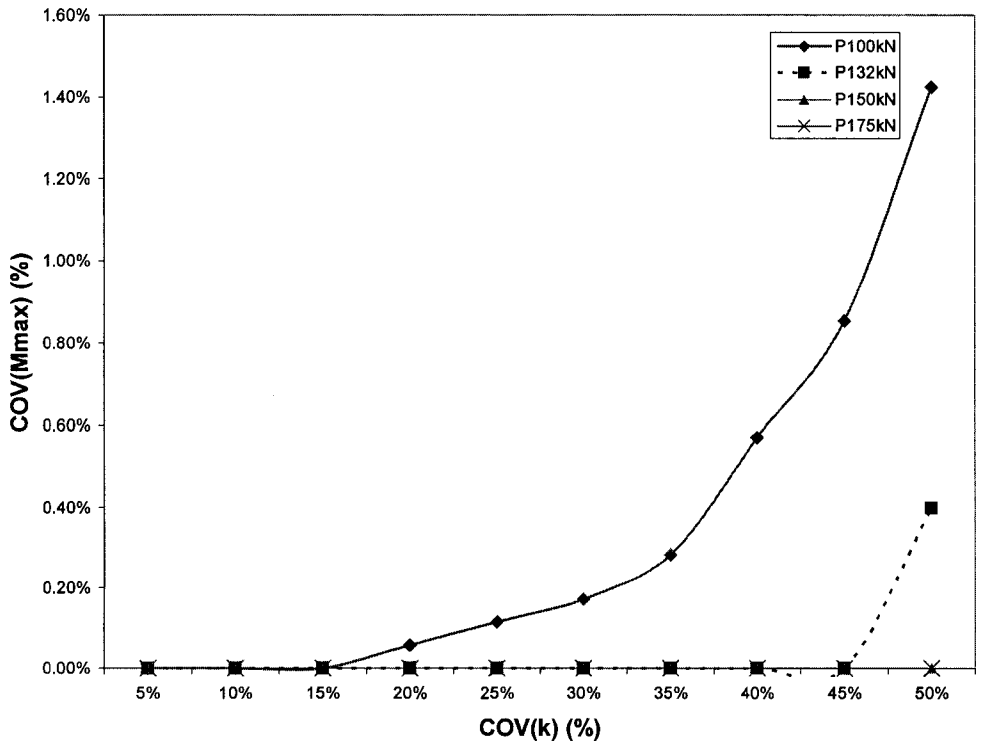

Fig. D.10 COV(M_{Max}) for varying COV(k) in free head long pile (10T).

D.1.6 Probabilistic modeling of laterally loaded free head single long pile (10T) with 'γ'' as varying random design variable

Table D.21 Values of Y_{Top} for free head single long pile (10T) with varying 'γ'' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	8.7025	2.95	0.00304	0.00476	0.00597	0.00801
45%	7.049025	3.245	0.00303	0.00476	0.00597	0.00801
40%	5.5696	3.54	0.00303	0.00476	0.00597	0.008
35%	4.264225	3.835	0.00303	0.00475	0.00597	0.008
30%	3.1329	4.13	0.00303	0.00475	0.00596	0.008
25%	2.175625	4.425	0.00303	0.00475	0.00596	0.00799
20%	1.3924	4.72	0.00303	0.00475	0.00596	0.00799
15%	0.783225	5.015	0.00303	0.00474	0.00595	0.00798
10%	0.3481	5.31	0.00303	0.00474	0.00595	0.00798
5%	0.087025	5.605	0.00302	0.00474	0.00595	0.00798
0%	0	5.9	0.00302	0.00474	0.00595	0.00797
5%	0.087025	6.195	0.00302	0.00474	0.00594	0.00797
10%	0.3481	6.49	0.00302	0.00473	0.00594	0.00796
15%	0.783225	6.785	0.00302	0.00473	0.00594	0.00796
20%	1.3924	7.08	0.00302	0.00473	0.00593	0.00796
25%	2.175625	7.375	0.00302	0.00473	0.00593	0.00795
30%	3.1329	7.67	0.00302	0.00473	0.00593	0.00795
35%	4.264225	7.965	0.00301	0.00472	0.00593	0.00794
40%	5.5696	8.26	0.00301	0.00472	0.00592	0.00794
45%	7.049025	8.555	0.00301	0.00472	0.00592	0.00794
50%	8.7025	8.85	0.00301	0.00472	0.00592	0.00793

Table D.22. Values of M_{Max} for free head single long pile (10T) with varying 'γ'' and lateral load P.

			P=100 kN	P=132 kN	P=150 kN	P=175 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	8.7025	2.95	87.9	125	148	183
45%	7.049025	3.245	87.9	125	148	183
40%	5.5696	3.54	87.9	125	148	183
35%	4.264225	3.835	87.9	125	148	183
30%	3.1329	4.13	87.9	125	148	183
25%	2.175625	4.425	87.9	125	148	183
20%	1.3924	4.72	87.8	125	148	183
15%	0.783225	5.015	87.8	125	148	183
10%	0.3481	5.31	87.8	125	148	183
5%	0.087025	5.605	87.8	125	148	183
0%	0	5.9	87.8	125	148	183
5%	0.087025	6.195	87.8	125	148	183
10%	0.3481	6.49	87.8	125	148	183
15%	0.783225	6.785	87.7	125	148	183
20%	1.3924	7.08	87.7	125	148	183
25%	2.175625	7.375	87.7	125	148	183
30%	3.1329	7.67	87.7	125	148	183
35%	4.264225	7.965	87.7	125	148	183
40%	5.5696	8.26	87.7	125	148	183
45%	7.049025	8.555	87.6	125	148	183
50%	8.7025	8.85	87.6	125	148	183

Table D.23(a) Value of $COV(Y_{Top})$ for free head single long pile (10T) with varying 'γ' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	0.00E+00	0.000%
10%	0.3481	2.50E-11	0.166%	2.50E-11	0.105%
15%	0.783225	2.50E-11	0.166%	2.50E-11	0.105%
20%	1.3924	2.50E-11	0.166%	1.00E-10	0.211%
25%	2.175625	2.50E-11	0.166%	1.00E-10	0.211%
30%	3.1329	2.50E-11	0.166%	1.00E-10	0.211%
35%	4.264225	1.00E-10	0.331%	2.25E-10	0.316%
40%	5.5696	1.00E-10	0.331%	4.00E-10	0.422%
45%	7.049025	1.00E-10	0.331%	4.00E-10	0.422%
50%	8.7025	2.25E-10	0.497%	4.00E-10	0.422%

Table D.23(b) Value of $COV(Y_{Top})$ for free head single long pile (10T) with varying 'γ' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	2.50E-11	0.084%	2.50E-11	0.063%
10%	0.3481	2.50E-11	0.084%	1.00E-10	0.125%
15%	0.783225	2.50E-11	0.084%	1.00E-10	0.125%
20%	1.3924	2.25E-10	0.252%	2.25E-10	0.188%
25%	2.175625	2.25E-10	0.252%	4.00E-10	0.251%
30%	3.1329	2.25E-10	0.252%	6.25E-10	0.314%
35%	4.264225	4.00E-10	0.336%	9.00E-10	0.376%
40%	5.5696	6.25E-10	0.420%	9.00E-10	0.376%
45%	7.049025	6.25E-10	0.420%	1.23E-09	0.439%
50%	8.7025	6.25E-10	0.420%	1.60E-09	0.502%

Table D.24(a) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'γ' and lateral load 100 kN and 132 kN.

		P=100 kN		P=132 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	0.087025	0	0.000%	0	0.000%
10%	0.3481	0	0.000%	0	0.000%
15%	0.783225	0.0025	0.057%	0	0.000%
20%	1.3924	0.0025	0.057%	0	0.000%
25%	2.175625	0.01	0.114%	0	0.000%
30%	3.1329	0.01	0.114%	0	0.000%
35%	4.264225	0.01	0.114%	0	0.000%
40%	5.5696	0.01	0.114%	0	0.000%
45%	7.049025	0.0225	0.171%	0	0.000%
50%	8.7025	0.0225	0.171%	0	0.000%

Table D.24(b) Value of COV(M_{Max}) for free head single long pile (10T) with varying 'γ' and lateral load 150 kN and 175 kN.

		P=150 kN		P=175 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	0.087025	0	0.000%	0	0.000%
10%	0.3481	0	0.000%	0	0.000%
15%	0.783225	0	0.000%	0	0.000%
20%	1.3924	0	0.000%	0	0.000%
25%	2.175625	0	0.000%	0	0.000%
30%	3.1329	0	0.000%	0	0.000%
35%	4.264225	0	0.000%	0	0.000%
40%	5.5696	0	0.000%	0	0.000%
45%	7.049025	0	0.000%	0	0.000%
50%	8.7025	0	0.000%	0	0.000%

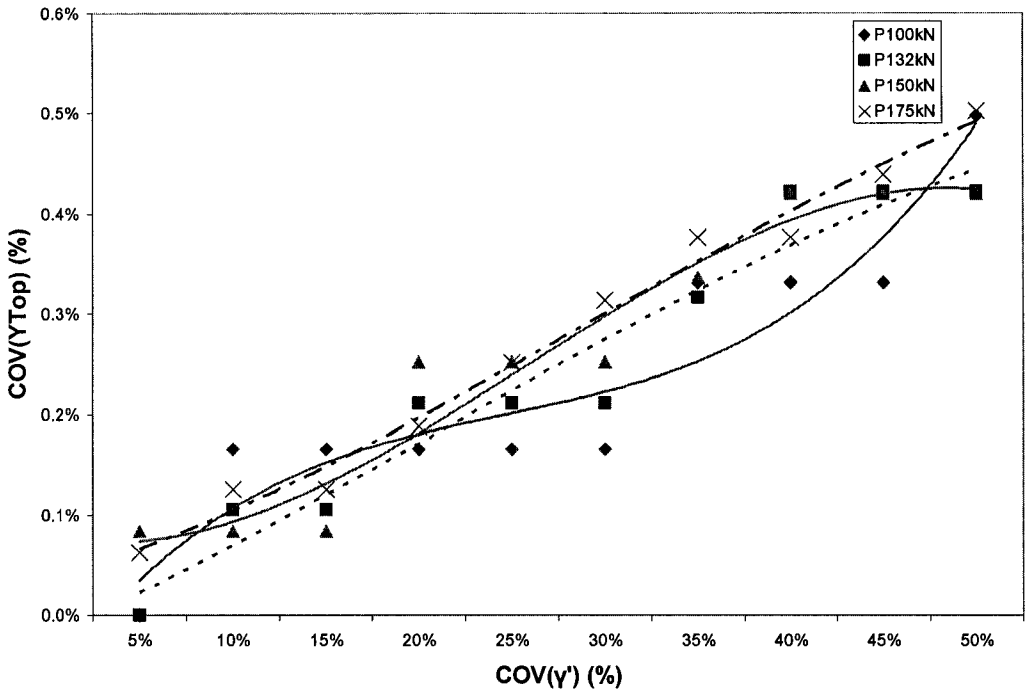

Fig. D.11 COV(Y_{Top}) for varying COV(γ') in free head long pile (10T).

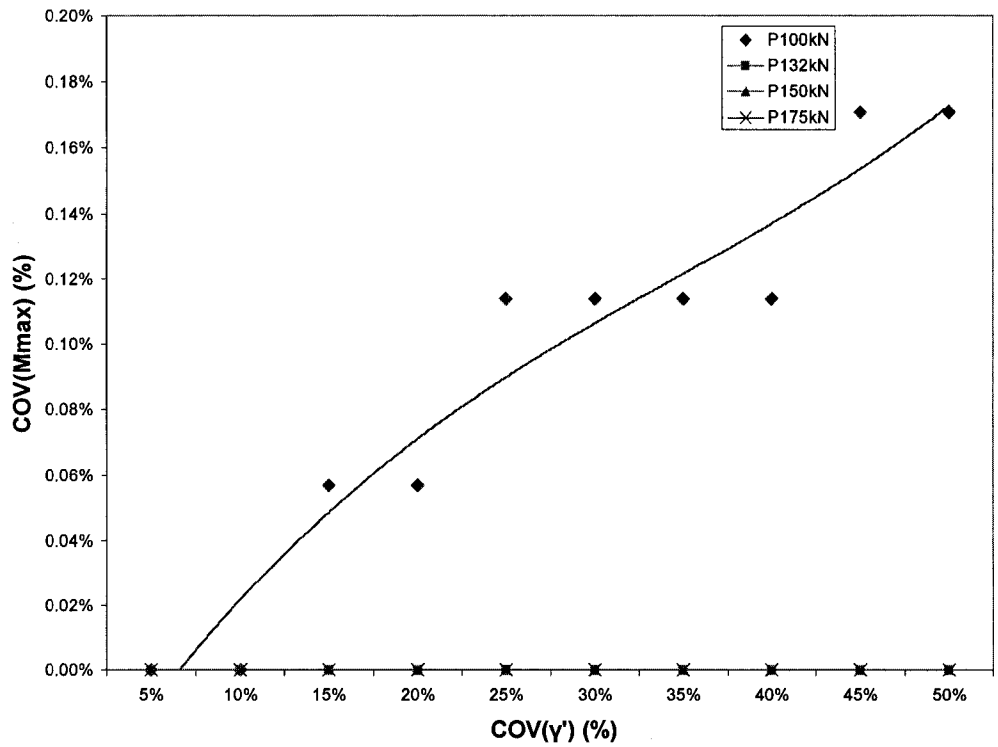

Fig. D.12 COV(M_{Max}) for varying COV(γ') in free head long pile (10T).

D.2 Reliability analysis of free head single long pile (10T).

D.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 100 kN

$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00998$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06\ m^2$

Table D.25 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 100 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	3.84	2.25E-08	6.78E-06	3.83
10%	6.76E-06	0.00E+00	6.76E-06	3.84	9.30E-08	6.85E-06	3.81
15%	6.76E-06	2.50E-11	6.76E-06	3.84	2.12E-07	6.97E-06	3.78
20%	6.76E-06	2.50E-11	6.76E-06	3.84	3.91E-07	7.15E-06	3.73
25%	6.76E-06	2.50E-11	6.76E-06	3.84	6.48E-07	7.41E-06	3.67
30%	6.76E-06	2.25E-10	6.76E-06	3.84	9.90E-07	7.75E-06	3.58
35%	6.76E-06	9.00E-10	6.76E-06	3.84	1.46E-06	8.22E-06	3.48
40%	6.76E-06	9.00E-10	6.76E-06	3.84	2.13E-06	8.89E-06	3.35
45%	6.76E-06	4.23E-09	6.76E-06	3.84	3.12E-06	9.88E-06	3.18
50%	6.76E-06	1.21E-08	6.77E-06	3.84	4.47E-06	1.12E-05	2.98

Table D.26 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 100 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	3.60E-09	6.76E-06	3.84	4E-08	6.80E-06	3.83
10%	6.76E-06	1.44E-08	6.77E-06	3.83	5.76E-08	6.82E-06	3.82
15%	6.76E-06	3.42E-08	6.79E-06	3.83	8.12E-08	6.84E-06	3.82
20%	6.76E-06	6.00E-08	6.82E-06	3.82	9.61E-08	6.86E-06	3.81
25%	6.76E-06	9.30E-08	6.85E-06	3.81	1.26E-07	6.89E-06	3.80
30%	6.76E-06	1.33E-07	6.89E-06	3.80	1.64E-07	6.92E-06	3.79
35%	6.76E-06	1.81E-07	6.94E-06	3.79	4.90E-07	7.25E-06	3.71
40%	6.76E-06	2.35E-07	7.00E-06	3.77	7.48E-07	7.51E-06	3.64
45%	6.76E-06	2.92E-07	7.05E-06	3.76	8.65E-07	7.62E-06	3.61
50%	6.76E-06	3.54E-07	7.11E-06	3.74	1.01E-06	7.77E-06	3.58

Table D.27 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 100 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.84	0.00E+00	6.76E-06	3.84
10%	6.76E-06	2.50E-11	6.76E-06	3.84	2.50E-11	6.76E-06	3.84
15%	6.76E-06	2.50E-11	6.76E-06	3.84	2.50E-11	6.76E-06	3.84
20%	6.76E-06	2.50E-11	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
25%	6.76E-06	2.50E-11	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
30%	6.76E-06	2.50E-11	6.76E-06	3.84	4.00E-10	6.76E-06	3.84
35%	6.76E-06	1.00E-10	6.76E-06	3.84	9.00E-10	6.76E-06	3.84
40%	6.76E-06	1.00E-10	6.76E-06	3.84	2.02E-09	6.76E-06	3.84
45%	6.76E-06	1.00E-10	6.76E-06	3.84	3.60E-09	6.76E-06	3.84
50%	6.76E-06	2.25E-10	6.76E-06	3.84	5.63E-09	6.77E-06	3.84

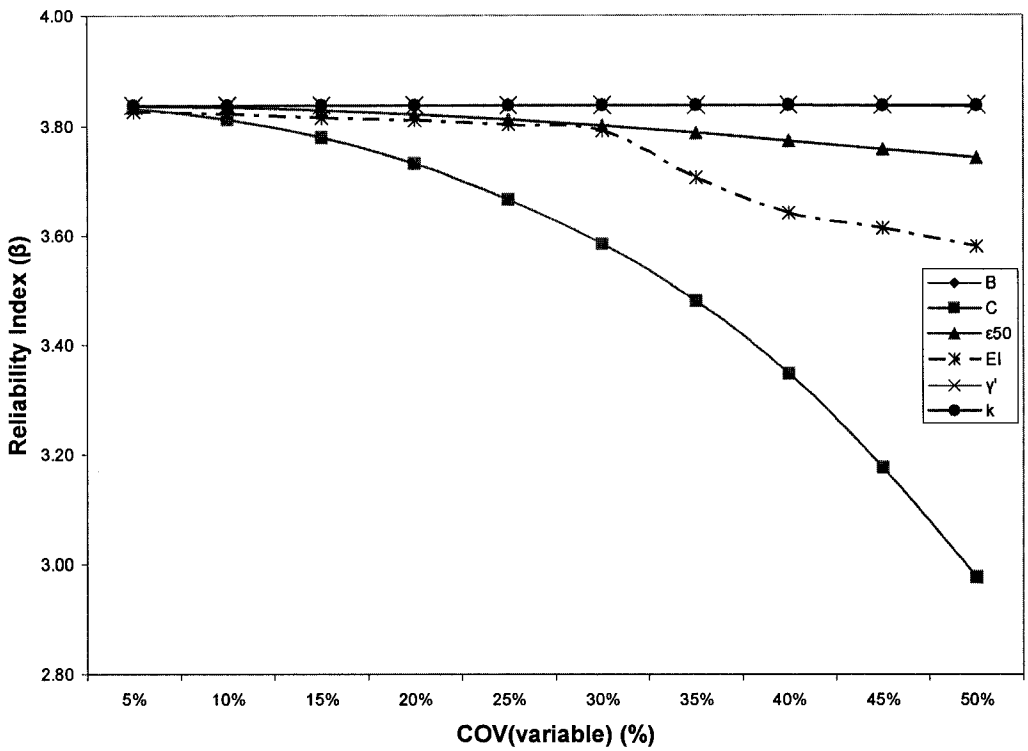

Fig. D.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single long pile (10T) at 100 kN lateral load.

For lateral load 132 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00826 \text{ m}$$

Table D.28 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 132 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.00E-10	6.76E-06	3.18	6.76E-08	6.83E-06	3.16
10%	6.76E-06	6.25E-10	6.76E-06	3.18	2.70E-07	7.03E-06	3.12
15%	6.76E-06	1.60E-09	6.76E-06	3.18	6.32E-07	7.39E-06	3.04
20%	6.76E-06	3.02E-09	6.76E-06	3.18	1.23E-06	7.99E-06	2.92
25%	6.76E-06	8.10E-09	6.77E-06	3.18	2.04E-06	8.80E-06	2.78
30%	6.76E-06	1.82E-08	6.78E-06	3.17	3.15E-06	9.91E-06	2.62
35%	6.76E-06	3.42E-08	6.79E-06	3.17	4.82E-06	1.16E-05	2.43
40%	6.76E-06	7.56E-08	6.84E-06	3.16	6.79E-06	1.35E-05	2.24
45%	6.76E-06	1.60E-07	6.92E-06	3.14	9.52E-06	1.63E-05	2.05
50%	6.76E-06	3.14E-07	7.07E-06	3.11	1.45E-05	2.12E-05	1.79

Table D.29 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 132 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	7.22E-09	6.77E-06	3.18	1.09E-07	6.87E-06	3.15
10%	6.76E-06	3.06E-08	6.79E-06	3.17	1.60E-07	6.92E-06	3.14
15%	6.76E-06	6.76E-08	6.83E-06	3.16	2.21E-07	6.98E-06	3.13
20%	6.76E-06	1.19E-07	6.88E-06	3.15	3.03E-07	7.06E-06	3.11
25%	6.76E-06	2.07E-07	6.97E-06	3.13	3.97E-07	7.16E-06	3.09
30%	6.76E-06	2.92E-07	7.05E-06	3.11	5.04E-07	7.26E-06	3.06
35%	6.76E-06	3.91E-07	7.15E-06	3.09	1.49E-06	8.25E-06	2.88
40%	6.76E-06	5.04E-07	7.26E-06	3.06	2.18E-06	8.94E-06	2.76
45%	6.76E-06	6.24E-07	7.38E-06	3.04	2.54E-06	9.30E-06	2.71
50%	6.76E-06	7.57E-07	7.52E-06	3.01	2.99E-06	9.75E-06	2.64

Table D.30 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 132 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.18	0.00E+00	6.76E-06	3.18
10%	6.76E-06	2.50E-11	6.76E-06	3.18	2.50E-11	6.76E-06	3.18
15%	6.76E-06	2.50E-11	6.76E-06	3.18	2.50E-11	6.76E-06	3.18
20%	6.76E-06	1.00E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
25%	6.76E-06	1.00E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
30%	6.76E-06	1.00E-10	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
35%	6.76E-06	2.25E-10	6.76E-06	3.18	2.50E-11	6.76E-06	3.18
40%	6.76E-06	4.00E-10	6.76E-06	3.18	2.50E-11	6.76E-06	3.18
45%	6.76E-06	4.00E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
50%	6.76E-06	4.00E-10	6.76E-06	3.18	9.00E-10	6.76E-06	3.18

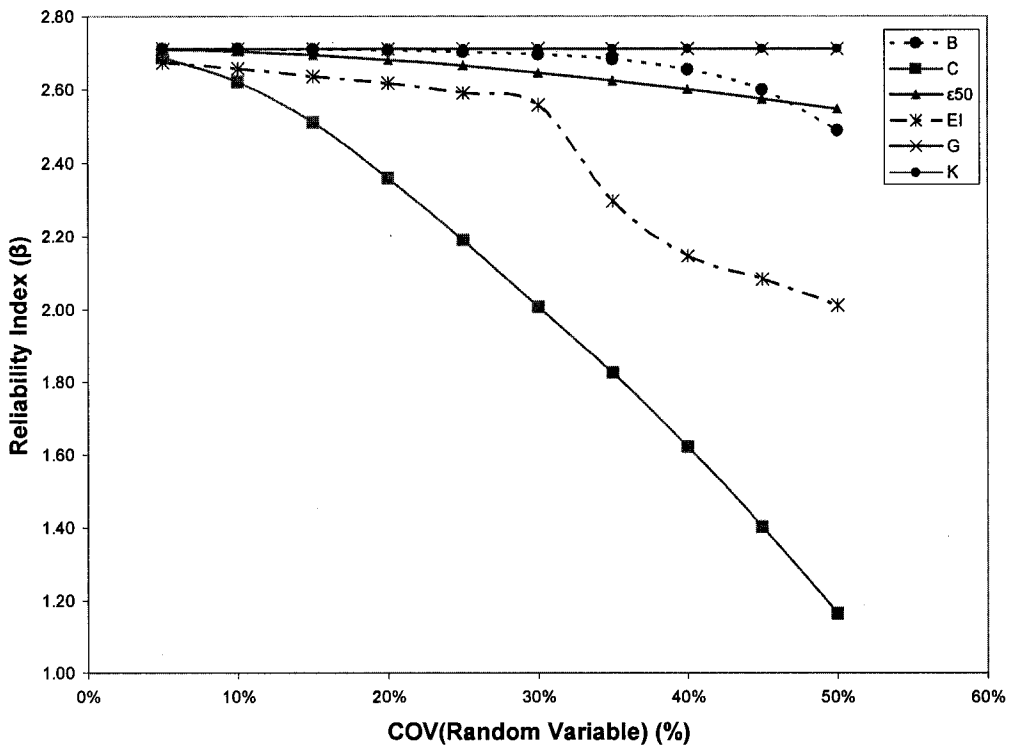

Fig. D.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single long pile (10T) at 132 kN lateral load.

For lateral load 150 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00705 \text{ m}$$

Table D.31 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 150 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	6.25E-10	6.76E-06	2.71	1.16E-07	6.88E-06	2.69
10%	6.76E-06	3.60E-09	6.76E-06	2.71	4.76E-07	7.24E-06	2.62
15%	6.76E-06	9.03E-09	6.77E-06	2.71	1.12E-06	7.88E-06	2.51
20%	6.76E-06	1.69E-08	6.78E-06	2.71	2.18E-06	8.94E-06	2.36
25%	6.76E-06	4.00E-08	6.80E-06	2.70	3.59E-06	1.04E-05	2.19
30%	6.76E-06	8.12E-08	6.84E-06	2.70	5.59E-06	1.24E-05	2.01
35%	6.76E-06	1.44E-07	6.90E-06	2.68	8.15E-06	1.49E-05	1.83
40%	6.76E-06	2.97E-07	7.06E-06	2.65	1.21E-05	1.89E-05	1.62
45%	6.76E-06	6.01E-07	7.36E-06	2.60	1.85E-05	2.53E-05	1.40
50%	6.76E-06	1.27E-06	8.03E-06	2.49	2.99E-05	3.67E-05	1.16

Table D.32 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 150 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	9.02E-09	6.77E-06	2.71	1.89E-07	6.95E-06	2.67
10%	6.76E-06	3.80E-08	6.80E-06	2.70	2.81E-07	7.04E-06	2.66
15%	6.76E-06	8.70E-08	6.85E-06	2.69	3.91E-07	7.15E-06	2.64
20%	6.76E-06	1.52E-07	6.91E-06	2.68	4.90E-07	7.25E-06	2.62
25%	6.76E-06	2.30E-07	6.99E-06	2.67	6.48E-07	7.41E-06	2.59
30%	6.76E-06	3.36E-07	7.10E-06	2.65	8.37E-07	7.60E-06	2.56
35%	6.76E-06	4.56E-07	7.22E-06	2.62	2.67E-06	9.43E-06	2.30
40%	6.76E-06	5.93E-07	7.35E-06	2.60	4.02E-06	1.08E-05	2.15
45%	6.76E-06	7.40E-07	7.50E-06	2.57	4.69E-06	1.14E-05	2.08
50%	6.76E-06	9.03E-07	7.66E-06	2.55	5.52E-06	1.23E-05	2.01

Table D.33 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 150 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
10%	6.76E-06	2.50E-11	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
15%	6.76E-06	2.50E-11	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
20%	6.76E-06	2.25E-10	6.76E-06	2.71	1.00E-10	6.76E-06	2.71
25%	6.76E-06	2.25E-10	6.76E-06	2.71	1.00E-10	6.76E-06	2.71
30%	6.76E-06	2.25E-10	6.76E-06	2.71	4.00E-10	6.76E-06	2.71
35%	6.76E-06	4.00E-10	6.76E-06	2.71	4.00E-10	6.76E-06	2.71
40%	6.76E-06	6.25E-10	6.76E-06	2.71	6.25E-10	6.76E-06	2.71
45%	6.76E-06	6.25E-10	6.76E-06	2.71	1.00E-10	6.76E-06	2.71
50%	6.76E-06	6.25E-10	6.76E-06	2.71	4.00E-10	6.76E-06	2.71

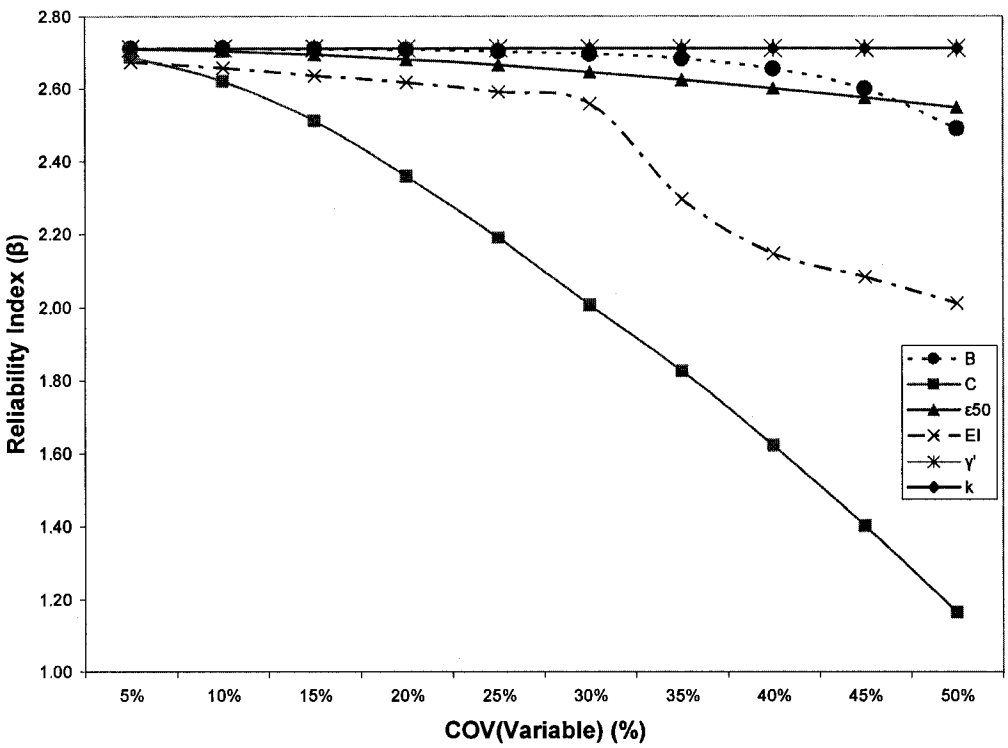

Fig. D.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single long pile (10T) at 150 kN lateral load.

For lateral load 175 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00503 \text{ m}$$

Table D.34 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 175 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	3.60E-09	6.76E-06	1.93	2.45E-07	7.01E-06	1.90
10%	6.76E-06	1.96E-08	6.78E-06	1.93	1.03E-06	7.79E-06	1.80
15%	6.76E-06	4.62E-08	6.81E-06	1.93	2.34E-06	9.10E-06	1.67
20%	6.76E-06	9.00E-08	6.85E-06	1.92	4.41E-06	1.12E-05	1.51
25%	6.76E-06	1.94E-07	6.95E-06	1.91	7.00E-06	1.38E-05	1.36
30%	6.76E-06	4.29E-07	7.19E-06	1.88	1.14E-05	1.82E-05	1.18
35%	6.76E-06	7.40E-07	7.50E-06	1.84	1.85E-05	2.53E-05	1.00
40%	6.76E-06	1.50E-06	8.26E-06	1.75	2.98E-05	3.66E-05	0.83
45%	6.76E-06	3.37E-06	1.01E-05	1.58	5.06E-05	5.73E-05	0.66
50%	6.76E-06	Failed	Failed	Failed	9.81E-05	1.05E-04	0.49

Table D.35 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 175 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.10E-08	6.77E-06	1.93	3.54E-07	7.11E-06	1.89
10%	6.76E-06	4.41E-08	6.80E-06	1.93	5.40E-07	7.30E-06	1.86
15%	6.76E-06	1.06E-07	6.87E-06	1.92	7.74E-07	7.53E-06	1.83
20%	6.76E-06	1.89E-07	6.95E-06	1.91	1.04E-06	7.80E-06	1.80
25%	6.76E-06	2.92E-07	7.05E-06	1.89	1.39E-06	8.15E-06	1.76
30%	6.76E-06	4.23E-07	7.18E-06	1.88	1.78E-06	8.54E-06	1.72
35%	6.76E-06	5.70E-07	7.33E-06	1.86	5.74E-06	1.25E-05	1.42
40%	6.76E-06	7.31E-07	7.49E-06	1.84	8.64E-06	1.54E-05	1.28
45%	6.76E-06	9.03E-07	7.66E-06	1.82	1.00E-05	1.68E-05	1.23
50%	6.76E-06	1.06E-06	7.82E-06	1.80	1.19E-05	1.87E-05	1.16

Table D.36 Reliability Index connected to Y_{Top} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 175 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
10%	6.76E-06	1.00E-10	6.76E-06	1.93	1.00E-10	6.76E-06	1.93
15%	6.76E-06	1.00E-10	6.76E-06	1.93	2.25E-10	6.76E-06	1.93
20%	6.76E-06	2.25E-10	6.76E-06	1.93	4.00E-10	6.76E-06	1.93
25%	6.76E-06	4.00E-10	6.76E-06	1.93	6.25E-10	6.76E-06	1.93
30%	6.76E-06	6.25E-10	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
35%	6.76E-06	9.00E-10	6.76E-06	1.93	1.00E-10	6.76E-06	1.93
40%	6.76E-06	9.00E-10	6.76E-06	1.93	1.00E-10	6.76E-06	1.93
45%	6.76E-06	1.23E-09	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
50%	6.76E-06	1.60E-09	6.76E-06	1.93	2.50E-11	6.76E-06	1.93

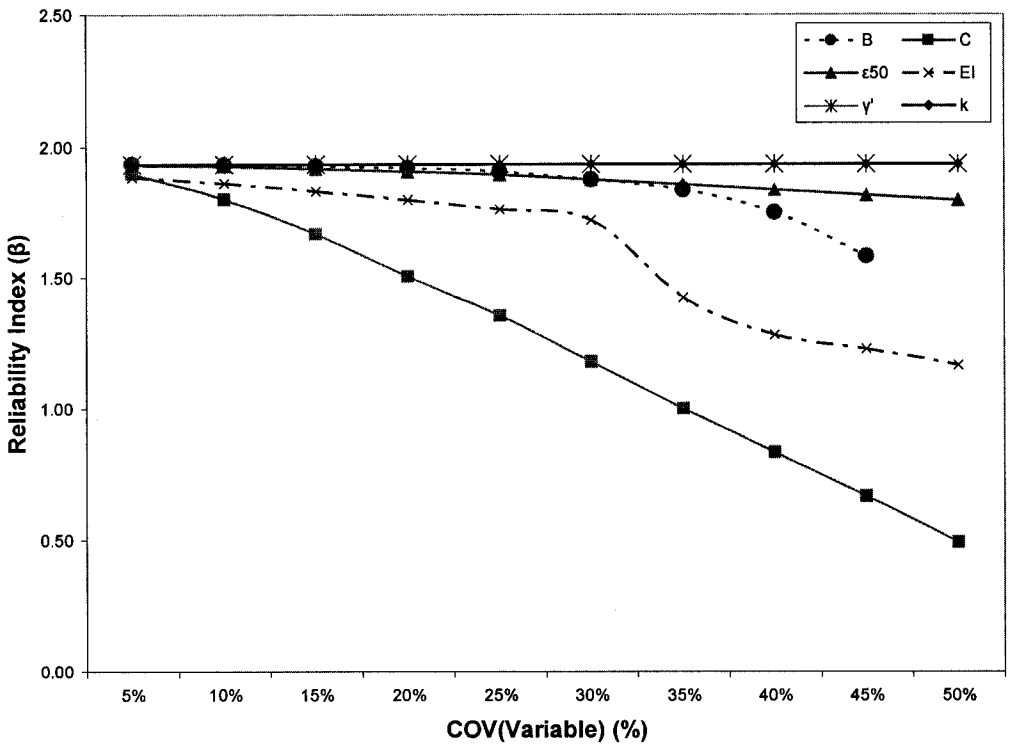

Fig. D.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head single long pile (10T) at 175 kN lateral load.

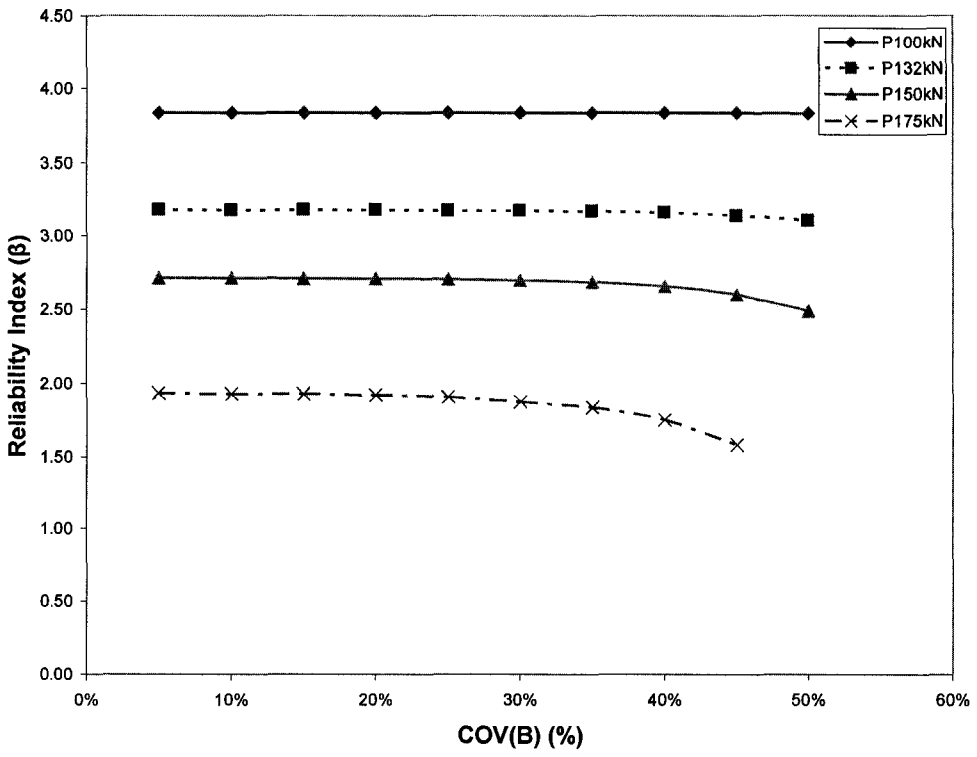

Fig. D.17 Reliability Index related to Y_{Top} for free head long pile with varying 'B'.

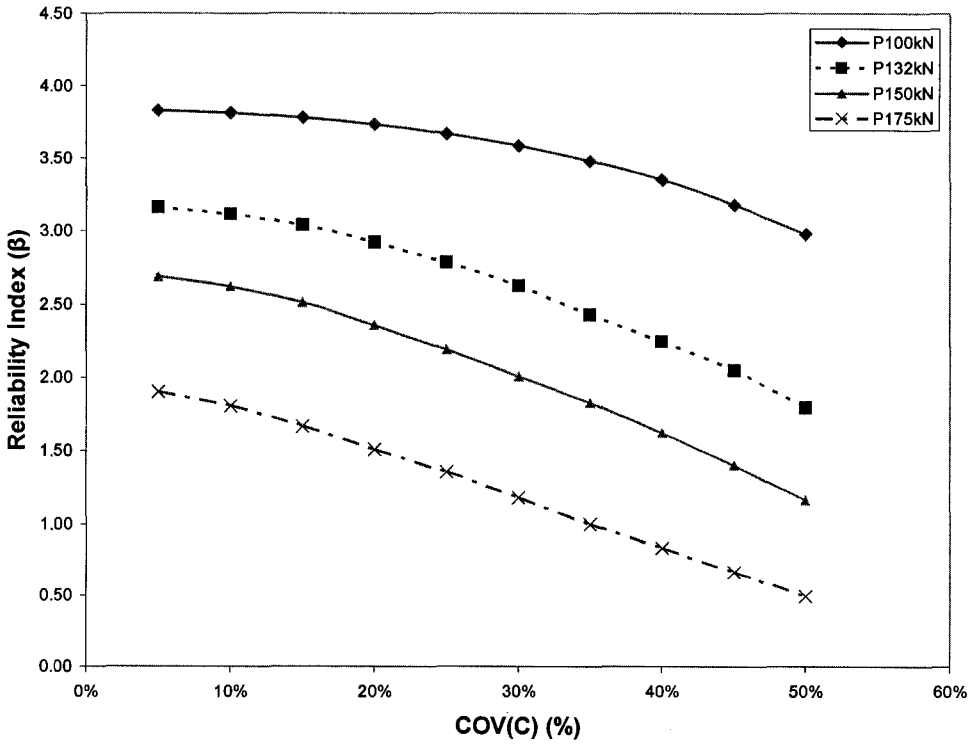

Fig. D.18 Reliability Index related to Y_{Top} for free head long pile with varying 'C'.

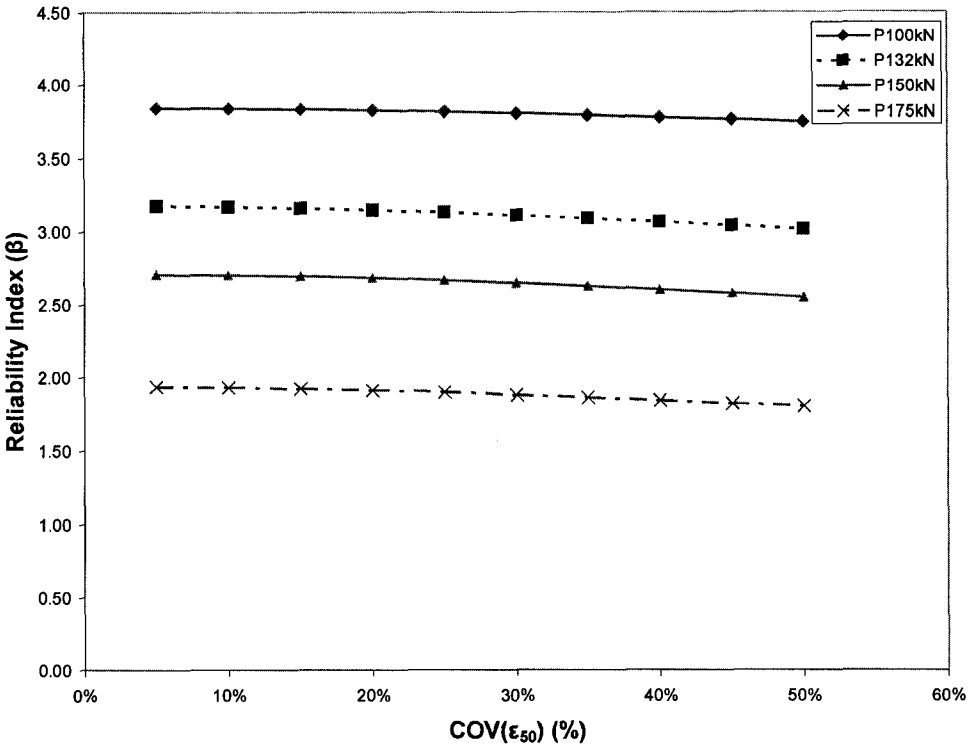

Fig. D.19 Reliability Index related to Y_{Top} for free head long pile with varying 'ε_{50}'.

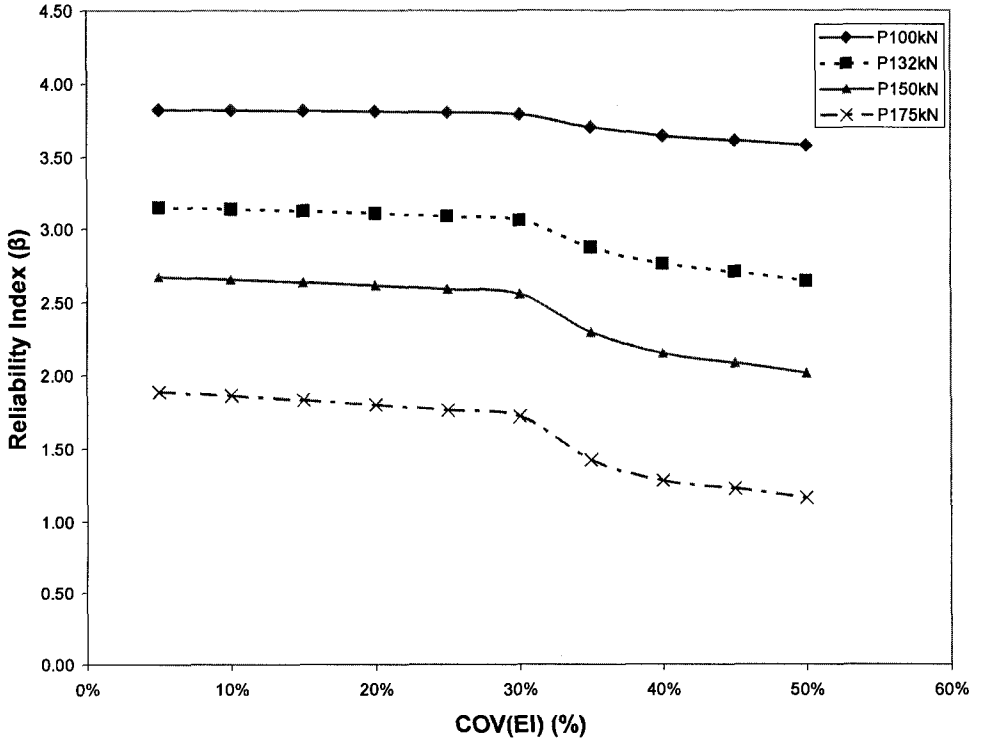

Fig. D.20 Reliability Index related to Y_{Top} for free head long pile with varying 'EI'.

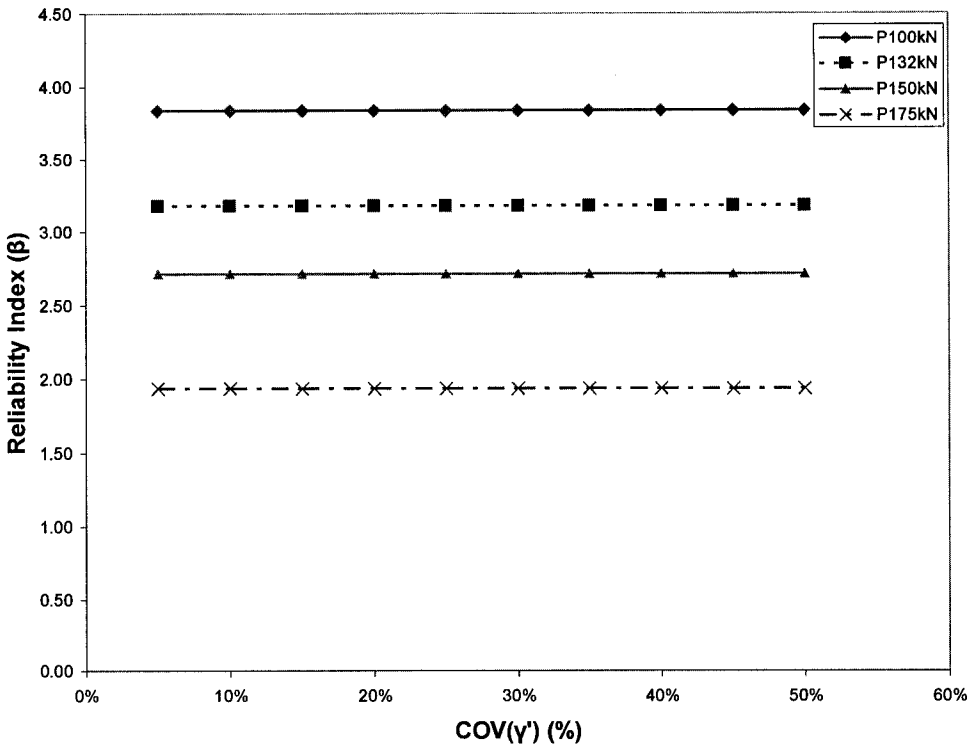

Fig. D.21 Reliability Index related to Y_{Top} for free head long pile with varying 'γ''.

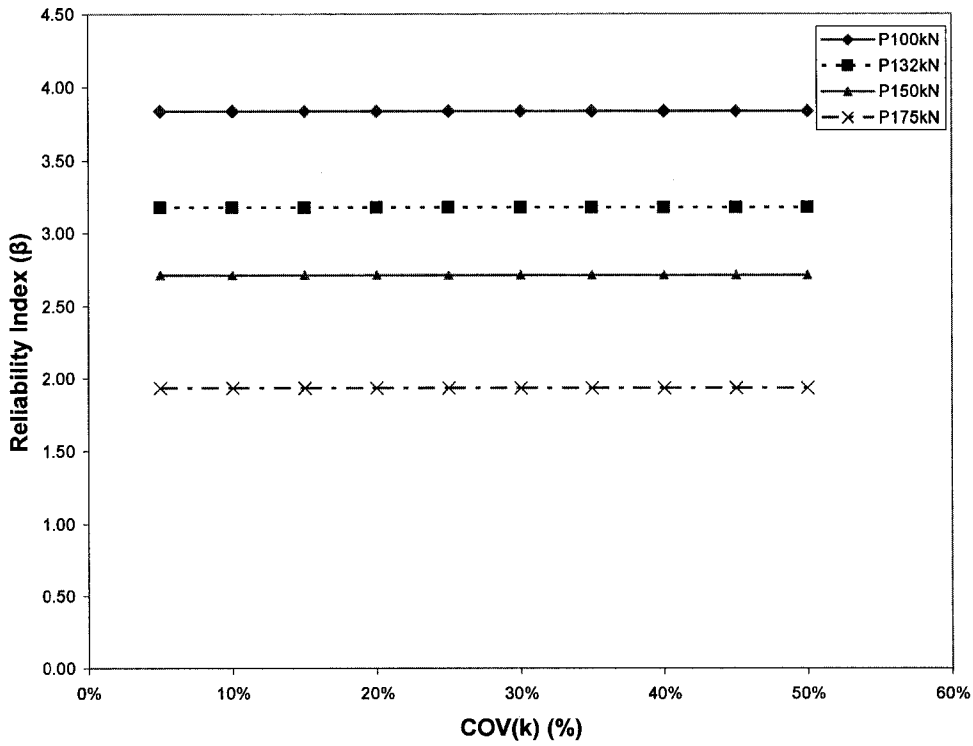

Fig. D.22 Reliability Index related to Y_{Top} for free head long pile with varying 'k'.

D.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 100 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 806.20 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table D.37 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 100 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.4425	4.51	2.7225	31972.1625	4.51
10%	31969.44	0.04	31969.48	4.51	10.89	31980.33	4.51
15%	31969.44	0.0625	31969.5025	4.51	25.5025	31994.9425	4.51
20%	31969.44	0.09	31969.53	4.51	44.2225	32013.6625	4.51
25%	31969.44	0.16	31969.6	4.51	67.24	32036.68	4.50
30%	31969.44	0.2025	31969.6425	4.51	98.01	32067.45	4.50
35%	31969.44	0.3025	31969.7425	4.51	138.0625	32107.5025	4.50
40%	31969.44	0.4225	31969.8625	4.51	203.0625	32172.5025	4.49
45%	31969.44	0.3025	31969.7425	4.51	277.2225	32246.6625	4.49
50%	31969.44	0.1225	31969.5625	4.51	376.36	32345.8	4.48

Table D.38 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 100 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.3025	31969.7425	4.51	1.21	31970.65	4.51
10%	31969.44	1.21	31970.65	4.51	1.69	31971.13	4.51
15%	31969.44	2.7225	31972.1625	4.51	2.4025	31971.8425	4.51
20%	31969.44	5.0625	31974.5025	4.51	3.8025	31973.2425	4.51
25%	31969.44	7.84	31977.28	4.51	4.84	31974.28	4.51
30%	31969.44	11.2225	31980.6625	4.51	6.25	31975.69	4.51
35%	31969.44	14.8225	31984.2625	4.51	14.44	31983.88	4.51
40%	31969.44	18.49	31987.93	4.51	23.04	31992.48	4.51
45%	31969.44	22.5625	31992.0025	4.51	26.01	31995.45	4.51
50%	31969.44	27.5625	31997.0025	4.51	28.6225	31998.0625	4.51

Table D.39 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 100 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.51	0	31969.44	4.51
10%	31969.44	0	31969.44	4.51	0	31969.44	4.51
15%	31969.44	0.0025	31969.4425	4.51	0	31969.44	4.51
20%	31969.44	0.0025	31969.4425	4.51	0.0025	31969.4425	4.51
25%	31969.44	0.01	31969.45	4.51	0.01	31969.45	4.51
30%	31969.44	0.01	31969.45	4.51	0.0225	31969.4625	4.51
35%	31969.44	0.01	31969.45	4.51	0.0625	31969.5025	4.51
40%	31969.44	0.01	31969.45	4.51	0.25	31969.69	4.51
45%	31969.44	0.0225	31969.4625	4.51	0.5625	31970.0025	4.51
50%	31969.44	0.0225	31969.4625	4.51	1.5625	31971.0025	4.51

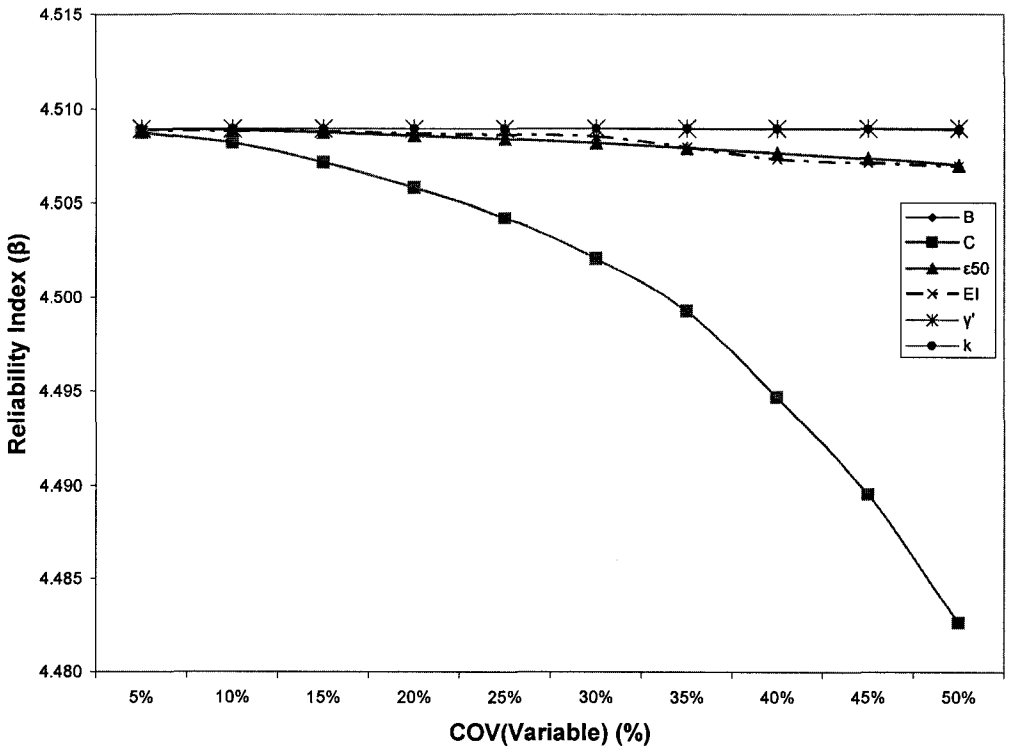

Fig. D.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single long pile (10T) at 100 kN lateral load.

For lateral load 132 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 769 \text{ kN.m}$$

Table D.40 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 132 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.30	6.25	31975.69	4.30
10%	31969.44	0	31969.44	4.30	25	31994.44	4.30
15%	31969.44	0	31969.44	4.30	56.25	32025.69	4.30
20%	31969.44	0.25	31969.69	4.30	100	32069.44	4.29
25%	31969.44	0.25	31969.69	4.30	169	32138.44	4.29
30%	31969.44	0.25	31969.69	4.30	272.25	32241.69	4.28
35%	31969.44	0.25	31969.69	4.30	400	32369.44	4.27
40%	31969.44	2.25	31971.69	4.30	529	32498.44	4.27
45%	31969.44	4	31973.44	4.30	676	32645.44	4.26
50%	31969.44	9	31978.44	4.30	930.25	32899.69	4.24

Table D.41 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 132 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.25	31969.69	4.30	1	31970.44	4.30
10%	31969.44	1	31970.44	4.30	1	31970.44	4.30
15%	31969.44	2.25	31971.69	4.30	1	31970.44	4.30
20%	31969.44	4	31973.44	4.30	4	31973.44	4.30
25%	31969.44	6.25	31975.69	4.30	4	31973.44	4.30
30%	31969.44	9	31978.44	4.30	4	31973.44	4.30
35%	31969.44	12.25	31981.69	4.30	12.25	31981.69	4.30
40%	31969.44	16	31985.44	4.30	25	31994.44	4.30
45%	31969.44	20.25	31989.69	4.30	25	31994.44	4.30
50%	31969.44	20.25	31989.69	4.30	30.25	31999.69	4.30

Table D.42 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 132 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.30	0	31969.44	4.30
10%	31969.44	0	31969.44	4.30	0	31969.44	4.30
15%	31969.44	0	31969.44	4.30	0	31969.44	4.30
20%	31969.44	0	31969.44	4.30	0	31969.44	4.30
25%	31969.44	0	31969.44	4.30	0	31969.44	4.30
30%	31969.44	0	31969.44	4.30	0	31969.44	4.30
35%	31969.44	0	31969.44	4.30	0	31969.44	4.30
40%	31969.44	0	31969.44	4.30	0	31969.44	4.30
45%	31969.44	0	31969.44	4.30	0	31969.44	4.30
50%	31969.44	0	31969.44	4.30	0.25	31969.69	4.30

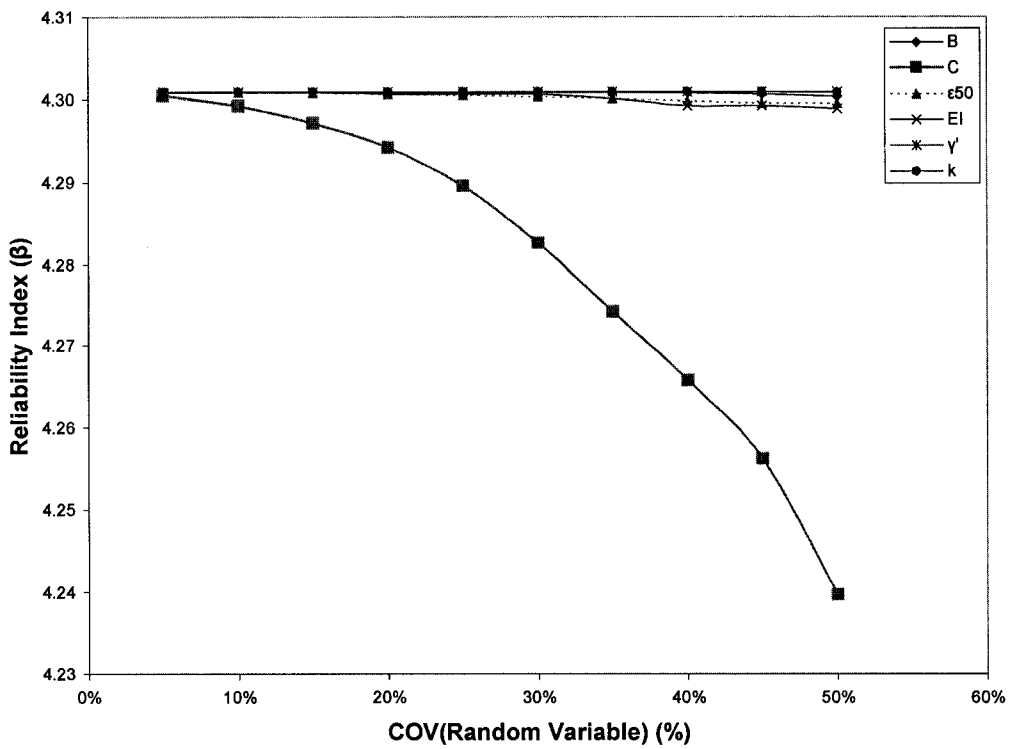

Fig. D.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single long pile (10T) at 132 kN lateral load.

For lateral load 150 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 746 \text{ kN.m}$$

Table D.43 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 150 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.17	9	31978.44	4.17
10%	31969.44	0	31969.44	4.17	36	32005.44	4.17
15%	31969.44	0.25	31969.69	4.17	81	32050.44	4.17
20%	31969.44	1	31970.44	4.17	169	32138.44	4.16
25%	31969.44	1	31970.44	4.17	272.25	32241.69	4.15
30%	31969.44	4	31973.44	4.17	420.25	32389.69	4.15
35%	31969.44	4	31973.44	4.17	576	32545.44	4.14
40%	31969.44	9	31978.44	4.17	812.25	32781.69	4.12
45%	31969.44	25	31994.44	4.17	1190.25	33159.69	4.10
50%	31969.44	56.25	32025.69	4.17	1681	33650.44	4.07

Table D.44 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 150 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.17	1	31970.44	4.17
10%	31969.44	1	31970.44	4.17	2.25	31971.69	4.17
15%	31969.44	1	31970.44	4.17	2.25	31971.69	4.17
20%	31969.44	1	31970.44	4.17	4	31973.44	4.17
25%	31969.44	4	31973.44	4.17	6.25	31975.69	4.17
30%	31969.44	4	31973.44	4.17	6.25	31975.69	4.17
35%	31969.44	4	31973.44	4.17	9	31978.44	4.17
40%	31969.44	6.25	31975.69	4.17	20.25	31989.69	4.17
45%	31969.44	6.25	31975.69	4.17	20.25	31989.69	4.17
50%	31969.44	9	31978.44	4.17	20.25	31989.69	4.17

Table D.45 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 150 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.17	0	31969.44	4.17
10%	31969.44	0	31969.44	4.17	0	31969.44	4.17
15%	31969.44	0	31969.44	4.17	0	31969.44	4.17
20%	31969.44	0	31969.44	4.17	0	31969.44	4.17
25%	31969.44	0	31969.44	4.17	0	31969.44	4.17
30%	31969.44	0	31969.44	4.17	0	31969.44	4.17
35%	31969.44	0	31969.44	4.17	0	31969.44	4.17
40%	31969.44	0	31969.44	4.17	0	31969.44	4.17
45%	31969.44	0	31969.44	4.17	0	31969.44	4.17
50%	31969.44	0	31969.44	4.17	0	31969.44	4.17

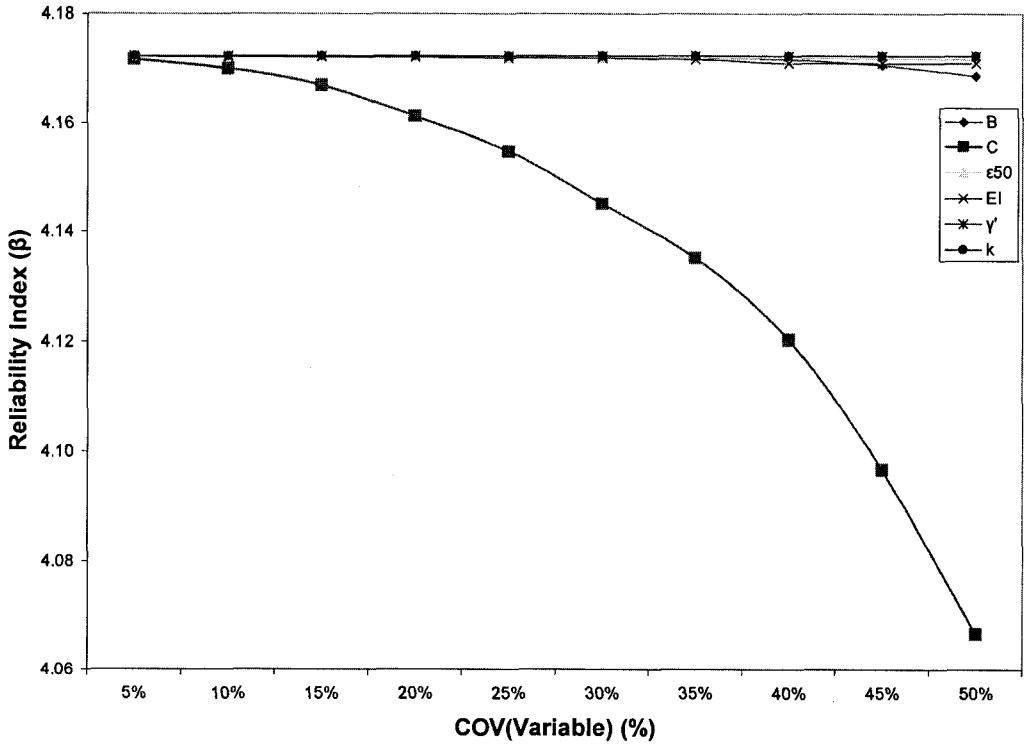

Fig. D.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single long pile (10T) at 150 kN lateral load.

For lateral load 175kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 711 \text{ kN.m}$$

T Table D.46 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'B' and 'C' and applied lateral load 175 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.98	20.25	31989.69	3.98
10%	31969.44	0.25	31969.69	3.98	72.25	32041.69	3.97
15%	31969.44	2.25	31971.69	3.98	169	32138.44	3.97
20%	31969.44	2.25	31971.69	3.98	289	32258.44	3.96
25%	31969.44	6.25	31975.69	3.98	462.25	32431.69	3.95
30%	31969.44	16	31985.44	3.98	702.25	32671.69	3.93
35%	31969.44	30.25	31999.69	3.97	1122.25	33091.69	3.91
40%	31969.44	72.25	32041.69	3.97	1640.25	33609.69	3.88
45%	31969.44	156.25	32125.69	3.97	2550.25	34519.69	3.83
50%	31969.44	Failed	Failed	Failed	4225	36194.44	3.74

Table D.47 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 175 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.98	1	31970.44	3.98
10%	31969.44	0.25	31969.69	3.98	2.25	31971.69	3.98
15%	31969.44	0.25	31969.69	3.98	2.25	31971.69	3.98
20%	31969.44	0.25	31969.69	3.98	2.25	31971.69	3.98
25%	31969.44	1	31970.44	3.98	2.25	31971.69	3.98
30%	31969.44	1	31970.44	3.98	2.25	31971.69	3.98
35%	31969.44	2.25	31971.69	3.98	6.25	31975.69	3.98
40%	31969.44	2.25	31971.69	3.98	12.25	31981.69	3.98
45%	31969.44	1	31970.44	3.98	12.25	31981.69	3.98
50%	31969.44	1	31970.44	3.98	12.25	31981.69	3.98

Table D.48 Reliability Index connected to M_{Max} for free head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 175 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.98	0	31969.44	3.98
10%	31969.44	0	31969.44	3.98	0	31969.44	3.98
15%	31969.44	0	31969.44	3.98	0	31969.44	3.98
20%	31969.44	0	31969.44	3.98	0	31969.44	3.98
25%	31969.44	0	31969.44	3.98	0	31969.44	3.98
30%	31969.44	0	31969.44	3.98	0	31969.44	3.98
35%	31969.44	0	31969.44	3.98	0	31969.44	3.98
40%	31969.44	0	31969.44	3.98	0	31969.44	3.98
45%	31969.44	0	31969.44	3.98	0	31969.44	3.98
50%	31969.44	0	31969.44	3.98	0	31969.44	3.98

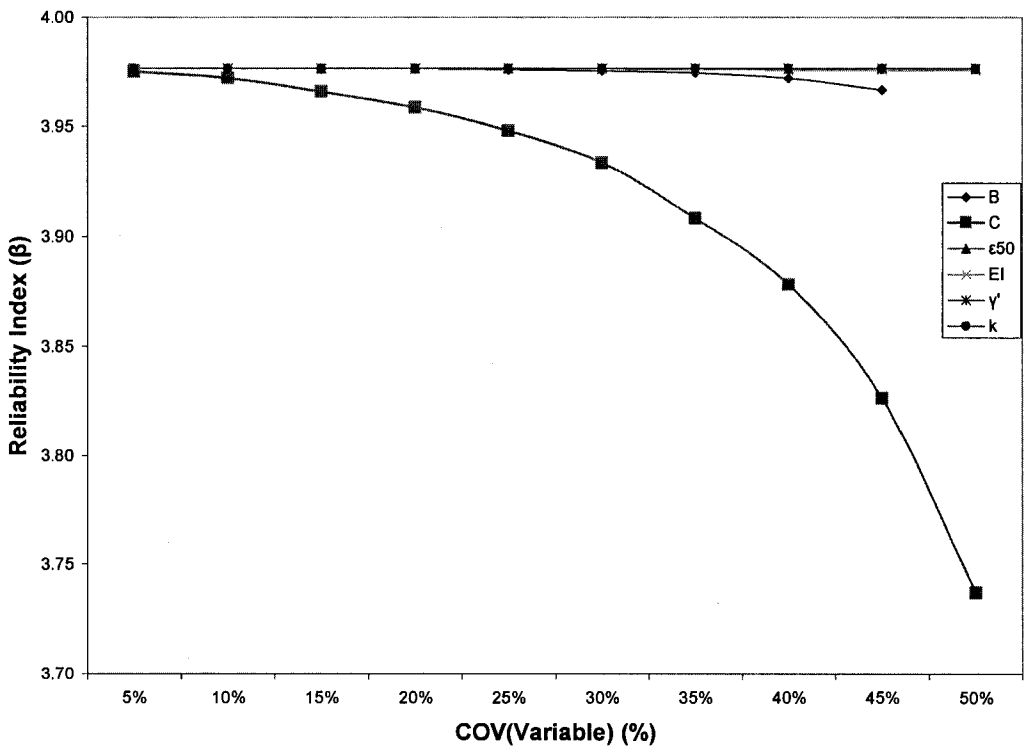

Fig. D.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in free head single long pile (10T) at 175 kN lateral load.

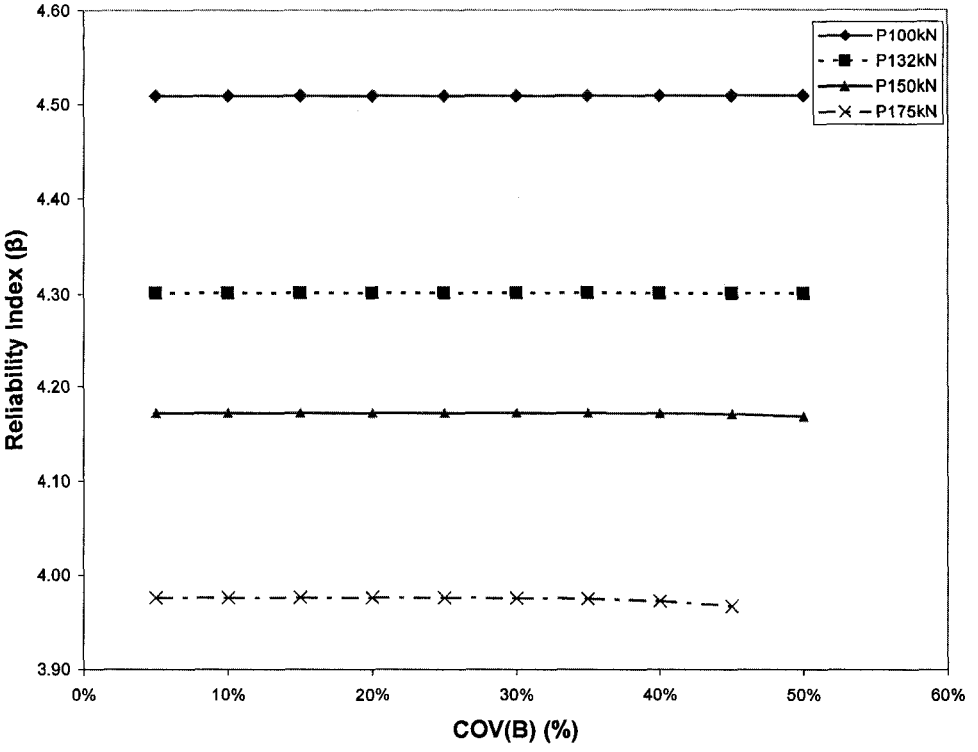

Fig. D.27 Reliability Index related to M_{Max} for free head long pile with varying 'B'.

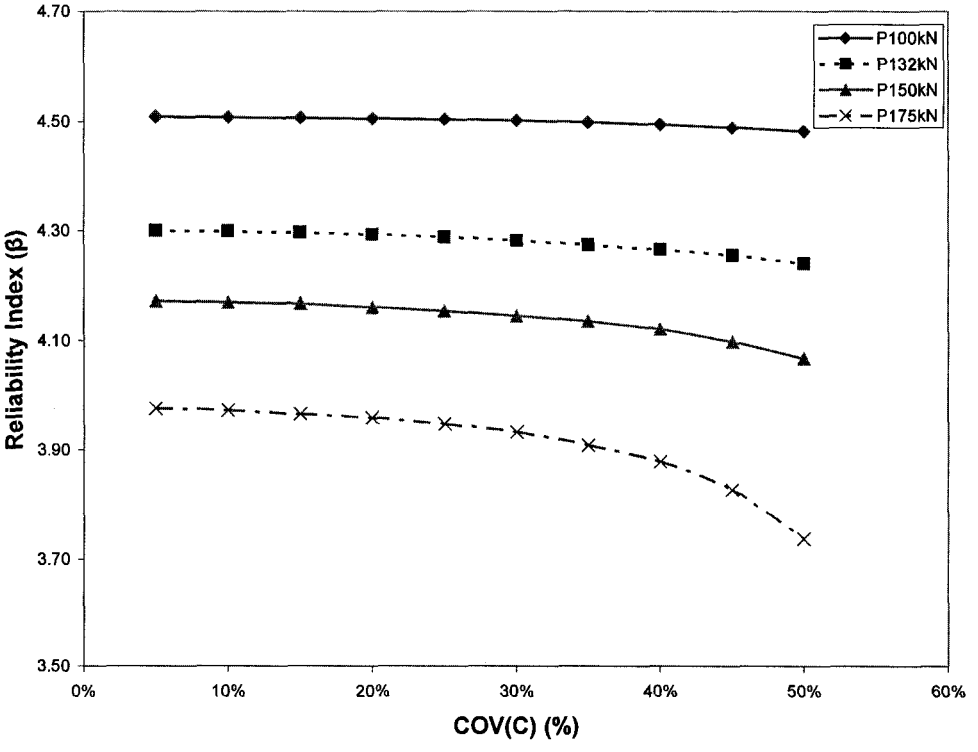

Fig. D.28 Reliability Index related to M_{Max} for free head long pile with varying 'C'.

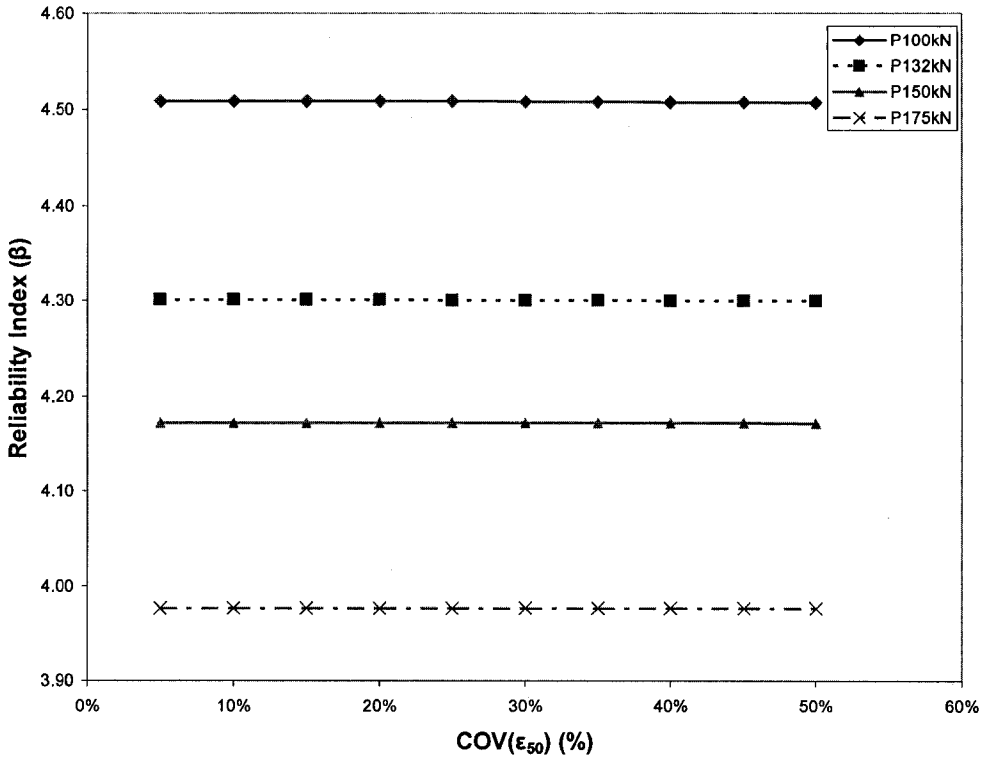

Fig. D.29 Reliability Index related to M_{Max} for free head long pile with varying 'ε_{50}'.

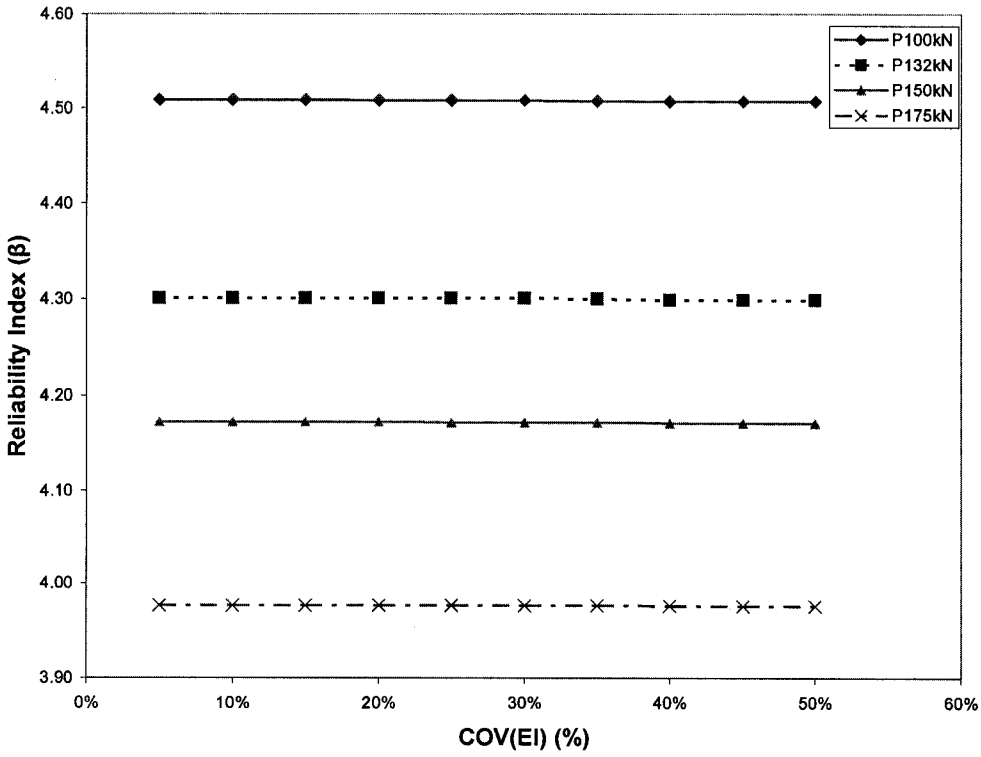

Fig. D.30 Reliability Index related to M_{Max} for free head long pile with varying 'EI'.

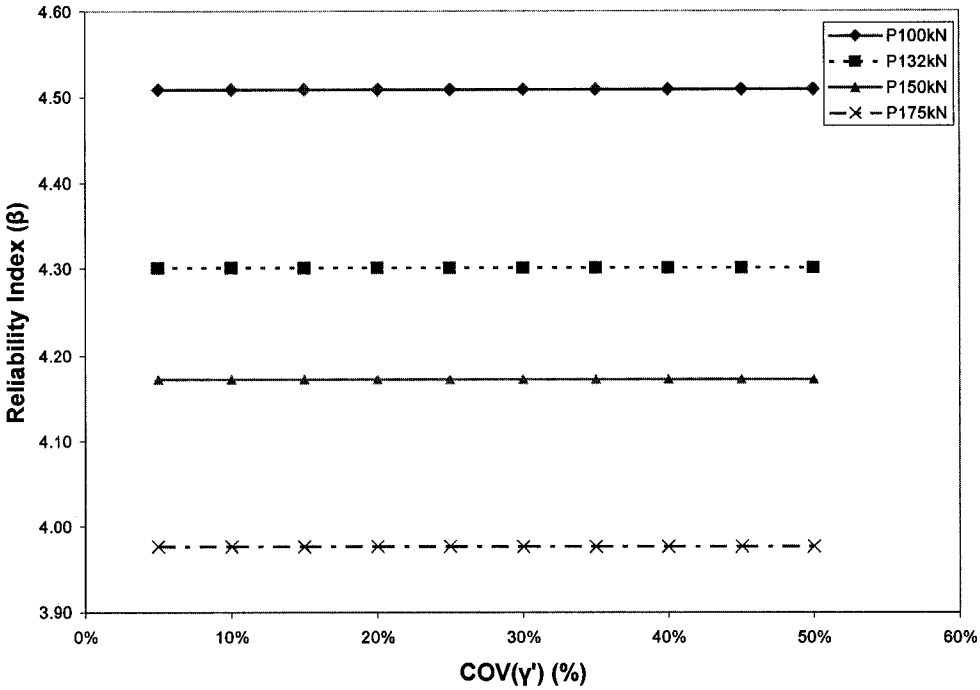

Fig. D.31 Reliability Index related to M_{Max} for free head long pile with varying 'γ'.

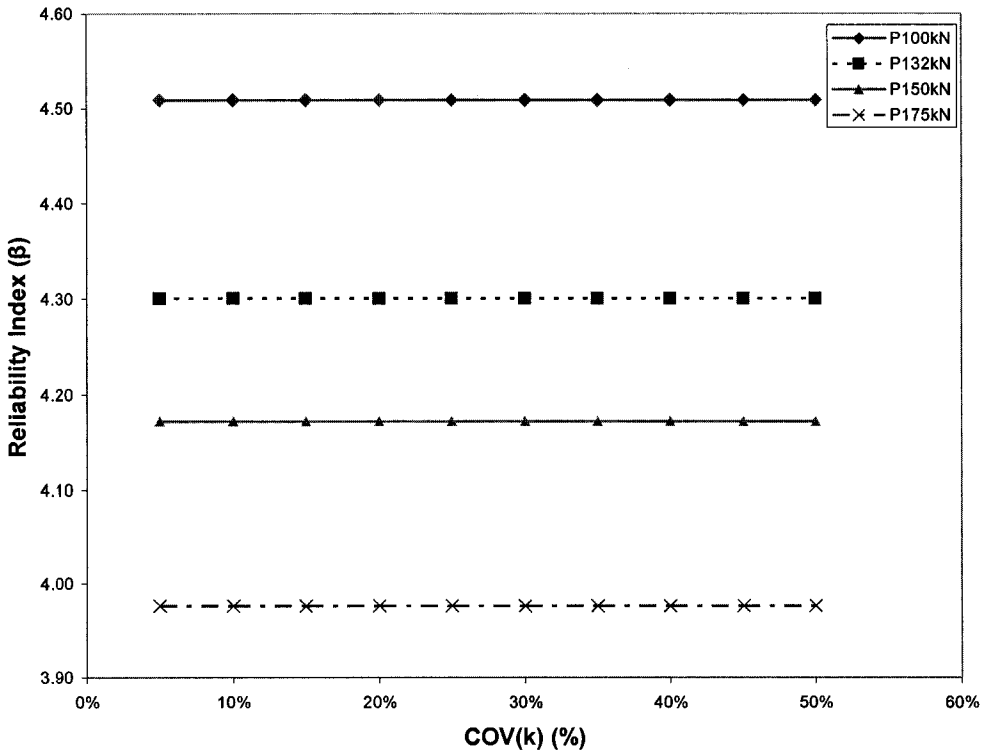

Fig. D.32 Reliability Index related to M_{Max} for free head long pile with varying 'k'.

APPENDIX E

LATERALLY LOADED FIXED HEAD SINGLE SHORT PILE (3T)

E.1.1 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'B' as varying random design variable

Table E.1. Values of Y_{Top} for fixed head single short pile (3T) with varying 'B' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	Ytop current (m)	Ytop current (m)	Ytop current (m)	Ytop current (m)
50%	0.064516	0.254	0.00529	Failed	Failed	Failed
45%	0.052258	0.2794	0.00461	Failed	Failed	Failed
40%	0.0412902	0.3048	0.00429	0.00783	Failed	Failed
35%	0.0316128	0.3302	0.00402	0.00678	Failed	Failed
30%	0.0232258	0.3556	0.00386	0.00615	0.00877	Failed
25%	0.016129	0.381	0.0037	0.00583	0.00785	0.0122
20%	0.0103226	0.4064	0.00362	0.00554	0.00731	0.0101
15%	0.0058064	0.4318	0.00356	0.00538	0.00692	0.00921
10%	0.0025806	0.4572	0.00346	0.00525	0.00669	0.00866
5%	0.0006452	0.4826	0.00343	0.0051	0.00652	0.00826
0%	0	0.508	0.00341	0.00503	0.00632	0.00802
5%	0.0006452	0.5334	0.0034	0.00497	0.00622	0.00777
10%	0.0025806	0.5588	0.00339	0.00493	0.00614	0.00763
15%	0.0058064	0.5842	0.00338	0.0049	0.00608	0.00752
20%	0.0103226	0.6096	0.00338	0.00487	0.00603	0.00743
25%	0.016129	0.635	0.00338	0.0048	0.00593	0.00735
30%	0.0232258	0.6604	0.00338	0.00479	0.0059	0.00724
35%	0.0316128	0.6858	0.00333	0.00478	0.00588	0.00719
40%	0.0412902	0.7112	0.00333	0.00477	0.00586	0.00715
45%	0.052258	0.7366	0.00333	0.00477	0.00585	0.00712
50%	0.064516	0.762	0.00333	0.00477	0.00584	0.0071

Table E.2. Values of M_{Max} for fixed head single short pile (3T) with varying 'B' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	Mmax current (kN-m)	Mmax current (kN-m)	Mmax current (kN-m)	Mmax current (kN-m)
50%	0.064516	0.254	-300	Failed	Failed	Failed
45%	0.052258	0.2794	-287	Failed	Failed	Failed
40%	0.0412902	0.3048	-281	-398	Failed	Failed
35%	0.0316128	0.3302	-275	-378	Failed	Failed
30%	0.0232258	0.3556	-272	-366	-447	Failed
25%	0.016129	0.381	-269	-360	-430	-542
20%	0.0103226	0.4064	-268	-355	-420	-505
15%	0.0058064	0.4318	-267	-352	-413	-489
10%	0.0025806	0.4572	-265	-349	-409	-479
5%	0.0006452	0.4826	-264	-346	-406	-471
0%	0	0.508	-264	-345	-402	-467
5%	0.0006452	0.5334	-264	-344	-400	-462
10%	0.0025806	0.5588	-264	-343	-398	-460
15%	0.0058064	0.5842	-264	-342	-397	-457
20%	0.0103226	0.6096	-264	-342	-396	-456
25%	0.016129	0.635	-264	-340	-394	-454
30%	0.0232258	0.6604	-264	-340	-393	-452
35%	0.0316128	0.6858	-263	-339	-393	-451
40%	0.0412902	0.7112	-263	-339	-392	-449
45%	0.052258	0.7366	-263	-339	-391	-449
50%	0.064516	0.762	-263	-339	-391	-448

Table E.3(a) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'B' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	2.25E-10	0.440%	4.23E-09	1.292%
10%	2.58E-03	1.23E-09	1.026%	2.56E-08	3.181%
15%	5.81E-03	8.10E-09	2.639%	5.76E-08	4.771%
20%	1.03E-02	1.44E-08	3.519%	1.12E-07	6.660%
25%	1.61E-02	2.56E-08	4.692%	2.65E-07	10.239%
30%	2.32E-02	5.76E-08	7.038%	4.62E-07	13.519%
35%	3.16E-02	1.19E-07	10.117%	1.00E-06	19.881%
40%	4.13E-02	2.30E-07	14.076%	2.34E-06	30.417%
45%	5.23E-02	4.10E-07	18.768%	Failed	Failed
50%	6.45E-02	9.60E-07	28.739%	Failed	Failed

Table E.3(b) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'B' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	2.25E-08	2.373%	6.00E-08	3.055%
10%	2.58E-03	7.56E-08	4.351%	2.65E-07	6.421%
15%	5.81E-03	1.76E-07	6.646%	7.14E-07	10.536%
20%	1.03E-02	4.10E-07	10.127%	1.78E-06	16.646%
25%	1.61E-02	9.22E-07	15.190%	5.88E-06	30.237%
30%	2.32E-02	2.06E-06	22.706%	Failed	Failed
35%	3.16E-02	Failed	Failed	Failed	Failed
40%	4.13E-02	Failed	Failed	Failed	Failed
45%	5.23E-02	Failed	Failed	Failed	Failed
50%	6.45E-02	Failed	Failed	Failed	Failed

Table E.4(a) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'B' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	0.00064516	0	0.000%	1	0.290%
10%	0.00258064	0.25	0.189%	9	0.870%
15%	0.00580644	2.25	0.568%	25	1.449%
20%	0.01032256	4	0.758%	42.25	1.884%
25%	0.016129	6.25	0.947%	100	2.899%
30%	0.02322576	16	1.515%	169	3.768%
35%	0.03161284	36	2.273%	380.25	5.652%
40%	0.04129024	81	3.409%	870.25	8.551%
45%	0.05225796	144	4.545%	Failed	Failed
50%	0.064516	342.25	7.008%	Failed	Failed

Table E.4(b) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'B' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	0.00064516	9	0.746%	20.25	0.964%
10%	0.00258064	30.25	1.368%	90.25	2.034%
15%	0.00580644	64	1.990%	256	3.426%
20%	0.01032256	144	2.985%	600.25	5.246%
25%	0.016129	324	4.478%	1936	9.422%
30%	0.02322576	729	6.716%	Failed	Failed
35%	0.03161284	Failed	Failed	Failed	Failed
40%	0.04129024	Failed	Failed	Failed	Failed
45%	0.05225796	Failed	Failed	Failed	Failed
50%	0.064516	Failed	Failed	Failed	Failed

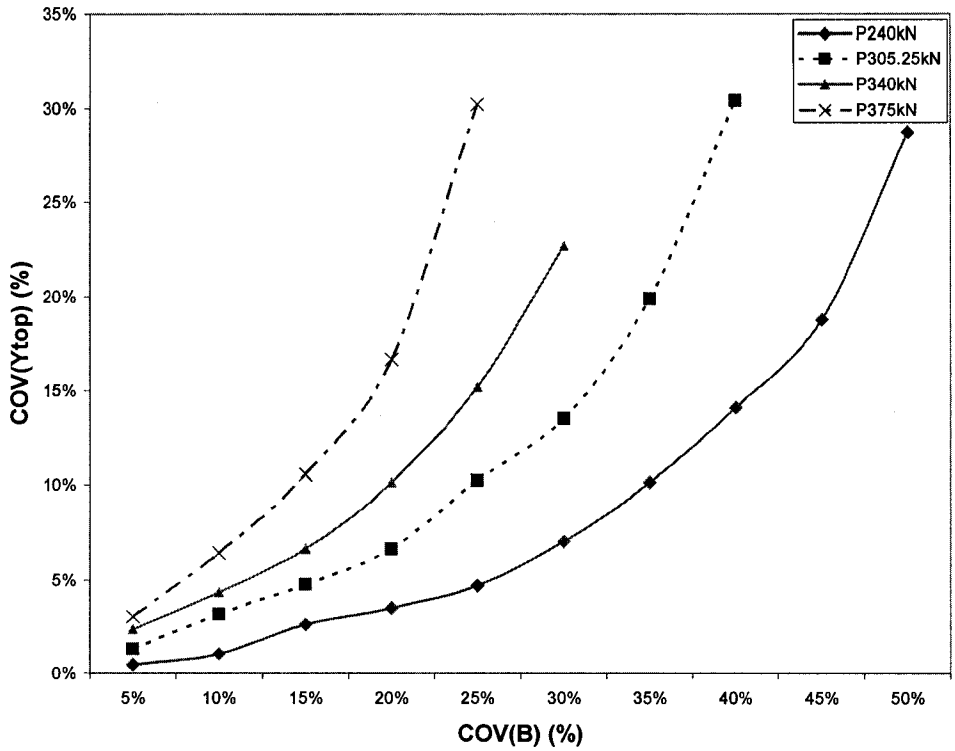

Fig. E.1 COV(Y_{Top}) for varying COV(B) in fixed head short pile (3T).

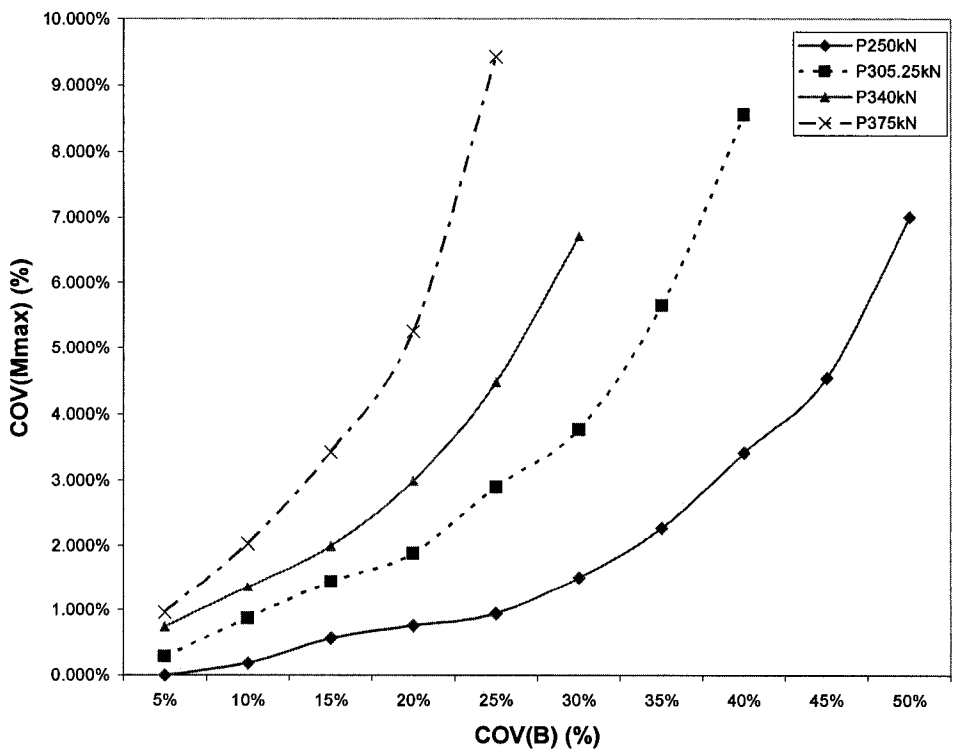

Fig. E.2 COV(M_{Max}) for varying COV(B) in fixed head short pile (3T).

E.1.2 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'C' as varying random design variable

Table E.5. Values of Y_{Top} for fixed head single short pile (3T) with varying 'C' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50.00%	1406.25	37.5	0.0113	Failed	Failed	Failed
45.00%	1139.0625	41.25	0.00909	Failed	Failed	Failed
40.00%	900	45	0.00758	0.0148	Failed	Failed
35.00%	689.0625	48.75	0.00653	0.0114	Failed	Failed
30.00%	506.25	52.5	0.00572	0.00954	0.0141	Failed
25.00%	351.5625	56.25	0.00516	0.00826	0.0114	0.0724
20.00%	225	60	0.00465	0.00729	0.00972	0.0138
15.00%	126.5625	63.75	0.00428	0.00653	0.00855	0.0115
10.00%	56.25	67.5	0.00393	0.00592	0.00765	0.00997
5.00%	14.0625	71.25	0.00368	0.00546	0.00692	0.00888
0.00%	0	75	0.00341	0.00503	0.00632	0.00802
5.00%	14.0625	78.75	0.00317	0.00471	0.00588	0.00732
10.00%	56.25	82.5	0.00303	0.00439	0.00545	0.00673
15.00%	126.5625	86.25	0.00291	0.00416	0.00513	0.0063
20.00%	225	90	0.00279	0.00391	0.0048	0.00587
25.00%	351.5625	93.75	0.00269	0.00374	0.00457	0.00555
30.00%	506.25	97.5	0.0026	0.00354	0.0043	0.00527
35.00%	689.0625	101.25	0.00251	0.00341	0.00413	0.00498
40.00%	900	105	0.00243	0.0033	0.00391	0.00476
45.00%	1139.0625	108.75	0.00236	0.00319	0.00378	0.00452
50.00%	1406.25	112.5	0.00229	0.00309	0.00366	0.00435

Table E.6. Values of M_{Max} for fixed head single short pile (3T) with varying 'C' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50.00%	1406.25	37.5	-409	Failed	Failed	Failed
45.00%	1139.0625	41.25	-374	Failed	Failed	Failed
40.00%	900	45	-348	-517	Failed	Failed
35.00%	689.0625	48.75	-329	-465	Failed	Failed
30.00%	506.25	52.5	-314	-433	-542	Failed
25.00%	351.5625	56.25	-303	-410	-498	-1250
20.00%	225	60	-292	-392	-468	-573
15.00%	126.5625	63.75	-284	-377	-447	-532
10.00%	56.25	67.5	-276	-365	-429	-505
5.00%	14.0625	71.25	-270	-355	-415	-484
0.00%	0	75	-264	-345	-402	-467
5.00%	14.0625	78.75	-258	-338	-392	-452
10.00%	56.25	82.5	-254	-330	-382	-440
15.00%	126.5625	86.25	-251	-324	-374	-430
20.00%	225	90	-248	-317	-366	-420
25.00%	351.5625	93.75	-245	-312	-360	-412
30.00%	506.25	97.5	-242	-307	-353	-405
35.00%	689.0625	101.25	-239	-304	-348	-397
40.00%	900	105	-236	-300	-342	-391
45.00%	1139.0625	108.75	-234	-297	-338	-384
50.00%	1406.25	112.5	-232	-294	-335	-379

Table E.7(a) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'C' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	6.50E-08	7.478%	1.41E-07	7.455%
10.00%	5.63E+01	2.03E-07	13.196%	5.85E-07	15.209%
15.00%	1.27E+02	4.69E-07	20.088%	1.40E-06	23.559%
20.00%	2.25E+02	8.65E-07	27.273%	2.86E-06	33.598%
25.00%	3.52E+02	1.53E-06	36.217%	5.11E-06	44.930%
30.00%	5.06E+02	2.43E-06	45.748%	9.00E-06	59.642%
35.00%	6.89E+02	4.04E-06	58.944%	1.60E-05	79.423%
40.00%	9.00E+02	6.63E-06	75.513%	3.31E-05	114.314%
45.00%	1.14E+03	1.13E-05	98.680%	Failed	Failed
50.00%	1.41E+03	2.03E-05	132.111%	Failed	Failed

Table E.7(b) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'C' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	2.70E-07	8.228%	6.08E-07	9.726%
10.00%	5.63E+01	1.21E-06	17.405%	2.62E-06	20.200%
15.00%	1.27E+02	2.92E-06	27.057%	6.76E-06	32.419%
20.00%	2.25E+02	6.05E-06	38.924%	1.57E-05	49.439%
25.00%	3.52E+02	1.17E-05	54.035%	1.12E-03	416.771%
30.00%	5.06E+02	2.40E-05	77.532%	Failed	Failed
35.00%	6.89E+02	Failed	Failed	Failed	Failed
40.00%	9.00E+02	Failed	Failed	Failed	Failed
45.00%	1.14E+03	Failed	Failed	Failed	Failed
50.00%	1.41E+03	Failed	Failed	Failed	Failed

Table E.8(a) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'C' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	14.0625	36	2.273%	72.25	2.464%
10.00%	56.25	121	4.167%	306.25	5.072%
15.00%	126.5625	272.25	6.250%	702.25	7.681%
20.00%	225	484	8.333%	1406.25	10.870%
25.00%	351.5625	841	10.985%	2401	14.203%
30.00%	506.25	1296	13.636%	3969	18.261%
35.00%	689.0625	2025	17.045%	6480.25	23.333%
40.00%	900	3136	21.212%	11772.25	31.449%
45.00%	1139.0625	4900	26.515%	Failed	Failed
50.00%	1406.25	7832.25	33.523%	Failed	Failed

Table E.8(b) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'C' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	14.0625	132.25	2.861%	256	3.426%
10.00%	56.25	552.25	5.846%	1056.25	6.959%
15.00%	126.5625	1332.25	9.080%	2601	10.921%
20.00%	225	2601	12.687%	5852.25	16.381%
25.00%	351.5625	4761	17.164%	175561	89.722%
30.00%	506.25	8930.25	23.507%	Failed	Failed
35.00%	689.0625	Failed	Failed	Failed	Failed
40.00%	900	Failed	Failed	Failed	Failed
45.00%	1139.0625	Failed	Failed	Failed	Failed
50.00%	1406.25	Failed	Failed	Failed	Failed

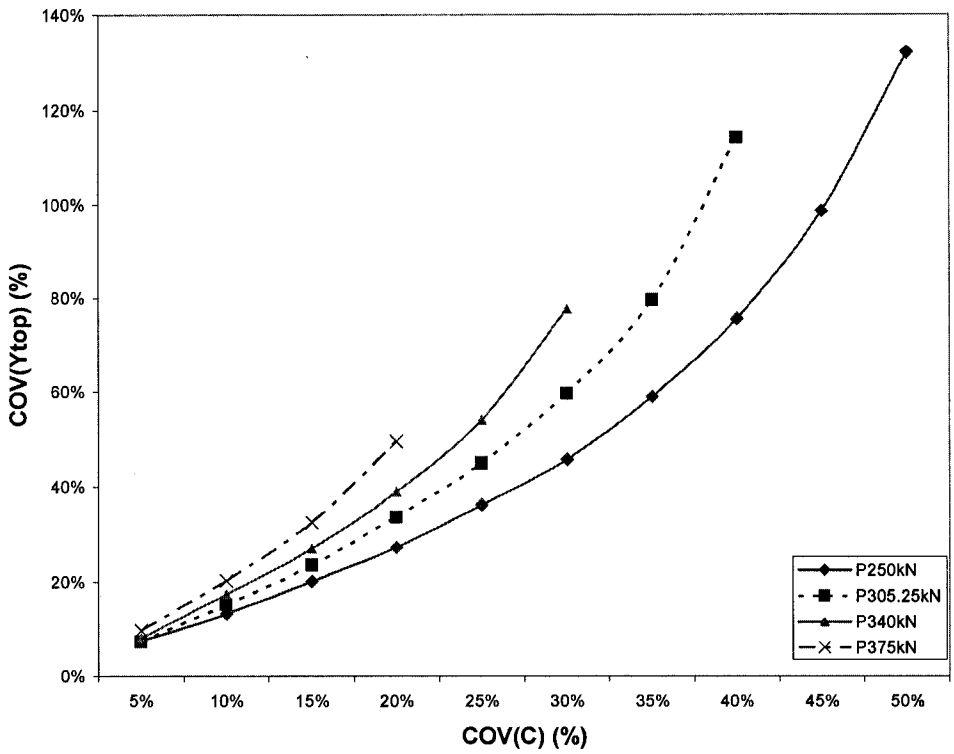

Fig. E.3 COV(Y_{Top}) for varying COV(C) in fixed head short pile (3T).

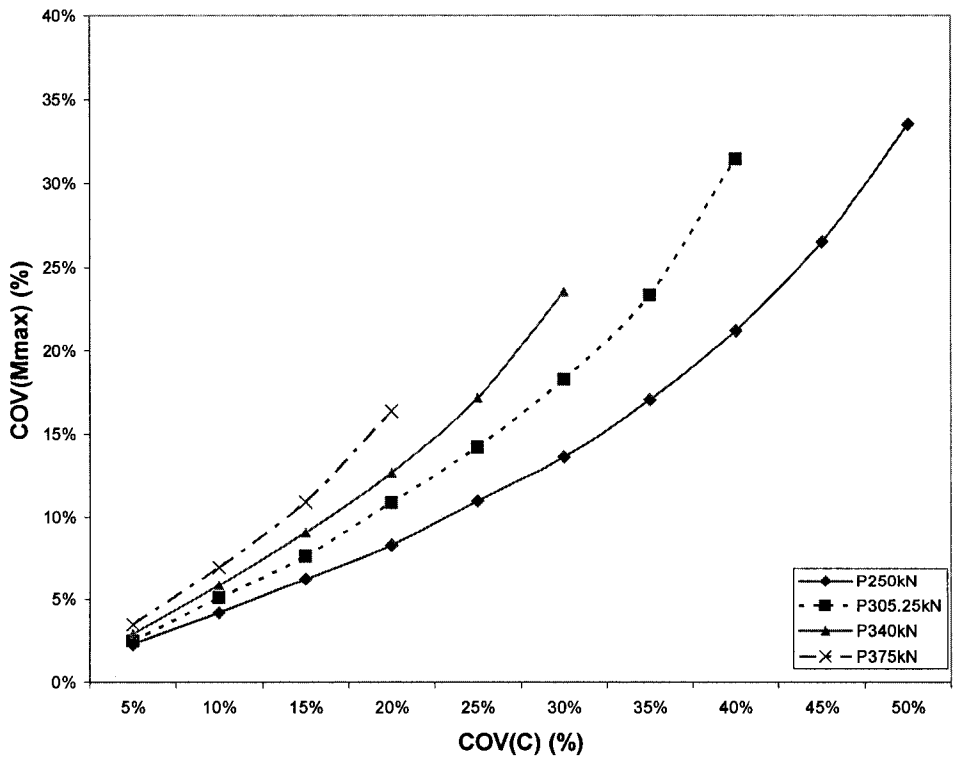

Fig. E.4 COV(M_{Max}) for varying COV(C) in fixed head short pile (3T).

E.1.3 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'ε_{50}' as varying random design variable

Table E.9. Values of Y_{Top} for fixed head single short pile (3T) with varying 'ε_{50}' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	0.00001225	0.0035	0.0026	0.00387	0.00502	0.00662
45%	9.9225E-06	0.00385	0.00267	0.00398	0.00514	0.00672
40%	0.00000784	0.0042	0.00275	0.00408	0.00526	0.00684
35%	6.0025E-06	0.00455	0.00282	0.00419	0.00539	0.00697
30%	0.00000441	0.0049	0.0029	0.0043	0.00552	0.00711
25%	3.0625E-06	0.00525	0.00297	0.00448	0.00566	0.00726
20%	0.00000196	0.0056	0.00305	0.00459	0.00579	0.00741
15%	1.1025E-06	0.00595	0.00312	0.0047	0.00593	0.00756
10%	0.00000049	0.0063	0.00326	0.00481	0.00606	0.00771
5%	1.225E-07	0.00665	0.00334	0.00492	0.00619	0.00787
0%	0	0.007	0.00341	0.00503	0.00632	0.00802
5%	1.225E-07	0.00735	0.00349	0.00514	0.00645	0.00802
10%	0.00000049	0.0077	0.00356	0.00525	0.00658	0.00833
15%	1.1025E-06	0.00805	0.00369	0.00535	0.00671	0.00848
20%	0.00000196	0.0084	0.00377	0.00546	0.00684	0.00863
25%	3.0625E-06	0.00875	0.00385	0.00557	0.00703	0.00878
30%	0.00000441	0.0091	0.00392	0.00567	0.00716	0.00892
35%	6.0025E-06	0.00945	0.00399	0.00583	0.00728	0.00907
40%	0.00000784	0.0098	0.00407	0.00594	0.00741	0.00922
45%	9.9225E-06	0.01015	0.00414	0.00604	0.00753	0.00936
50%	0.00001225	0.0105	0.00421	0.00615	0.00766	0.0095

Table E.10. Values of M_{Max} for fixed head single short pile (3T) with varying 'ε_{50}' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	0.00001225	0.0035	-246	-324	-382	-450
45%	9.9225E-06	0.00385	-247	-326	-383	-451
40%	0.00000784	0.0042	-249	-328	-383	-451
35%	6.0025E-06	0.00455	-251	-330	-387	-453
30%	0.00000441	0.0049	-253	-332	-389	-454
25%	3.0625E-06	0.00525	-254	-335	-391	-456
20%	0.00000196	0.0056	-256	-337	-393	-458
15%	1.1025E-06	0.00595	-258	-339	-395	-460
10%	0.00000049	0.0063	-261	-341	-398	-462
5%	1.225E-07	0.00665	-262	-343	-400	-465
0%	0	0.007	-264	-345	-402	-467
5%	1.225E-07	0.00735	-266	-347	-404	-467
10%	0.00000049	0.0077	-267	-349	-406	-471
15%	1.1025E-06	0.00805	-270	-351	-408	-474
20%	0.00000196	0.0084	-271	-353	-410	-476
25%	3.0625E-06	0.00875	-273	-354	-414	-478
30%	0.00000441	0.0091	-274	-356	-416	-480
35%	6.0025E-06	0.00945	-276	-359	-418	-483
40%	0.00000784	0.0098	-277	-361	-420	-485
45%	9.9225E-06	0.01015	-279	-363	-422	-487
50%	0.00001225	0.0105	-280	-365	-424	-489

Table E.11(a) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'ε_{50}' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	5.62E-09	2.199%	1.21E-08	2.187%
10%	4.90E-07	2.25E-08	4.399%	4.84E-08	4.374%
15%	1.10E-06	8.12E-08	8.358%	1.06E-07	6.461%
20%	1.96E-06	1.30E-07	10.557%	1.89E-07	8.648%
25%	3.06E-06	1.94E-07	12.903%	2.97E-07	10.835%
30%	4.41E-06	2.60E-07	14.956%	4.69E-07	13.618%
35%	6.00E-06	3.42E-07	17.155%	6.72E-07	16.302%
40%	7.84E-06	4.36E-07	19.355%	8.65E-07	18.489%
45%	9.92E-06	5.40E-07	21.554%	1.06E-06	20.477%
50%	1.23E-05	6.48E-07	23.607%	1.30E-06	22.664%

Table E.11(b) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'ε_{50}' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	1.69E-08	2.057%	5.62E-09	0.935%
10%	4.90E-07	6.76E-08	4.114%	9.61E-08	3.865%
15%	1.10E-06	1.52E-07	6.171%	2.12E-07	5.736%
20%	1.96E-06	2.76E-07	8.307%	3.72E-07	7.606%
25%	3.06E-06	4.69E-07	10.839%	5.78E-07	9.476%
30%	4.41E-06	6.72E-07	12.975%	8.19E-07	11.284%
35%	6.00E-06	8.93E-07	14.953%	1.10E-06	13.092%
40%	7.84E-06	1.16E-06	17.009%	1.42E-06	14.838%
45%	9.92E-06	1.43E-06	18.908%	1.74E-06	16.459%
50%	1.23E-05	1.74E-06	20.886%	2.07E-06	17.955%

Table E.12(a) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'ε_{50}' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	1.23E-07	4	0.758%	4	0.580%
10%	4.90E-07	9	1.136%	16	1.159%
15%	1.10E-06	36	2.273%	36	1.739%
20%	1.96E-06	56.25	2.841%	64	2.319%
25%	3.06E-06	90.25	3.598%	90.25	2.754%
30%	4.41E-06	110.25	3.977%	144	3.478%
35%	6.00E-06	156.25	4.735%	210.25	4.203%
40%	7.84E-06	196	5.303%	272.25	4.783%
45%	9.92E-06	256	6.061%	342.25	5.362%
50%	1.23E-05	289	6.439%	420.25	5.942%

Table E.12(b) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'ε_{50}' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	1.23E-07	4	0.498%	1	0.214%
10%	4.90E-07	16	0.995%	20.25	0.964%
15%	1.10E-06	42.25	1.617%	49	1.499%
20%	1.96E-06	72.25	2.114%	81	1.927%
25%	3.06E-06	132.25	2.861%	121	2.355%
30%	4.41E-06	182.25	3.358%	169	2.784%
35%	6.00E-06	240.25	3.856%	225	3.212%
40%	7.84E-06	342.25	4.602%	289	3.640%
45%	9.92E-06	380.25	4.851%	324	3.854%
50%	1.23E-05	441	5.224%	380.25	4.176%

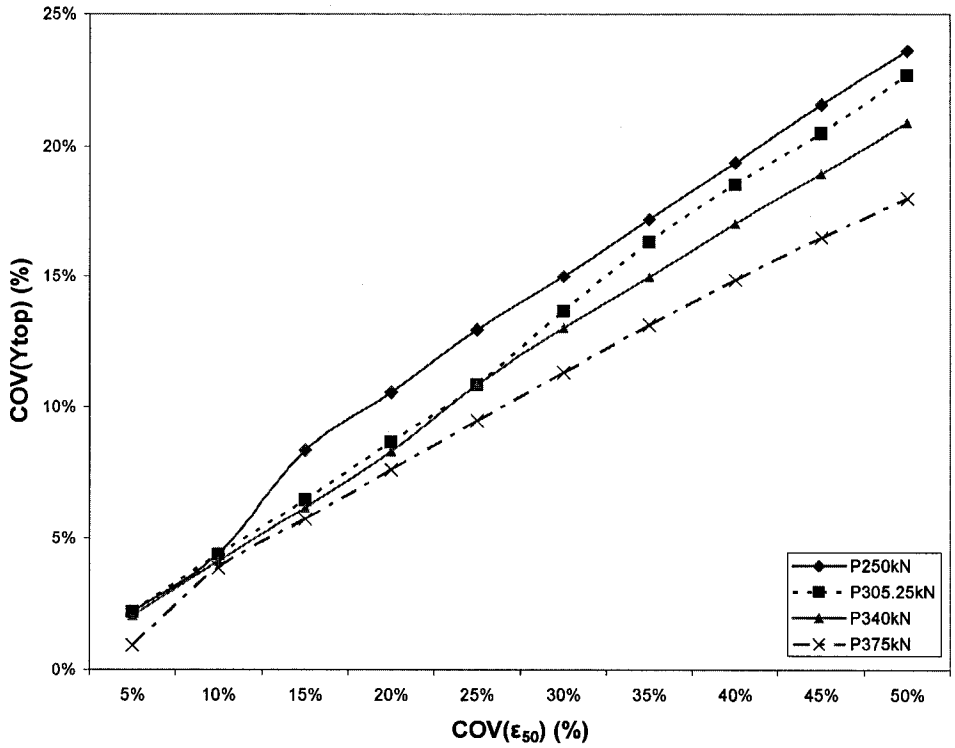

Fig. E.5 COV(Y_{Top}) for varying COV(ε_{50}) in fixed head short pile (3T).

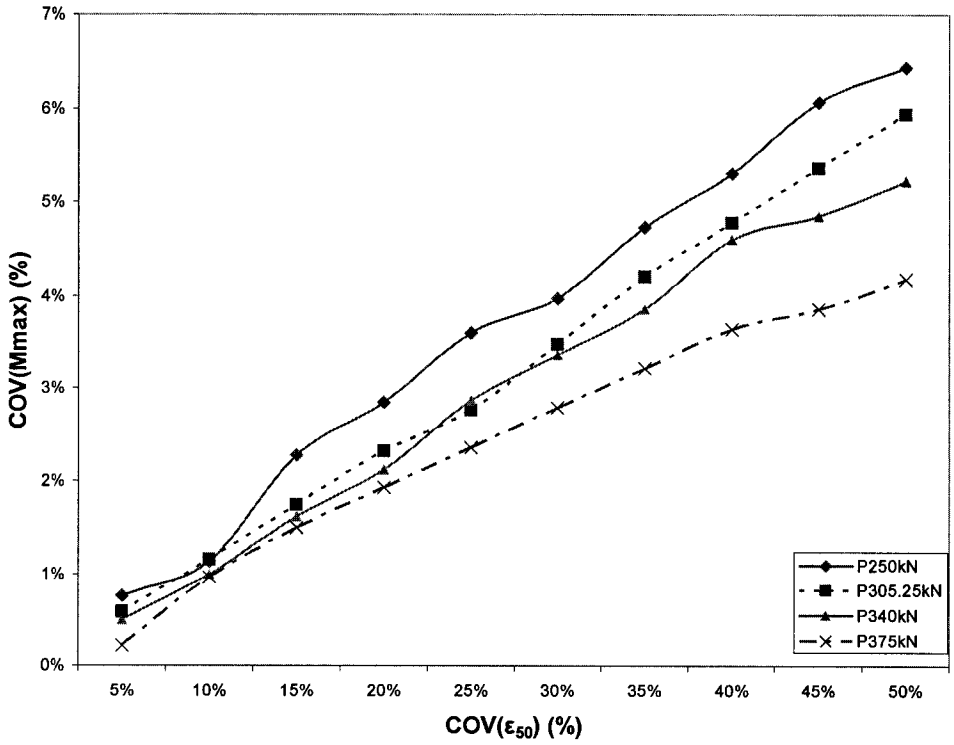

Fig. E.6 COV(M_{Max}) for varying COV(ε_{50}) in fixed head short pile (3T).

E.1.4 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'EI' as varying random design variable

Table E.13 Values of Y_{Top} for fixed head single short pile (3T) with varying 'EI' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	3.03E+09	55000	0.00478	0.00717	0.00924	0.0122
45%	2.45E+09	60500	0.00465	0.00695	0.00893	0.0117
40%	1.94E+09	66000	0.00453	0.00676	0.00867	0.0112
35%	1.48E+09	71500	0.00442	0.00658	0.00844	0.0109
30%	1.09E+09	77000	0.00375	0.00556	0.00709	0.00904
25%	7.56E+08	82500	0.00368	0.00545	0.00694	0.00877
20%	4.84E+08	88000	0.00362	0.00535	0.00681	0.00859
15%	2.72E+08	93500	0.00356	0.00526	0.00669	0.00843
10%	1.21E+08	99000	0.00351	0.00518	0.00652	0.00828
5%	3.03E+07	104500	0.00346	0.0051	0.00642	0.00815
0%	0.00E+00	110000	0.00341	0.00503	0.00632	0.00802
5%	3.03E+07	115500	0.00308	0.00451	0.00564	0.00705
10%	1.21E+08	121000	0.00304	0.00446	0.00557	0.00695
15%	2.72E+08	126500	0.00301	0.00441	0.00551	0.00687
20%	4.84E+08	132000	0.00298	0.00436	0.00545	0.00679
25%	7.56E+08	137500	0.00295	0.00431	0.00539	0.00671
30%	1.09E+09	143000	0.00292	0.00427	0.00533	0.00664
35%	1.48E+09	148500	0.0029	0.00417	0.00528	0.00657
40%	1.94E+09	154000	0.00262	0.00385	0.00479	0.00593
45%	2.45E+09	159500	0.0026	0.00381	0.00475	0.00588
50%	3.03E+09	165000	0.00258	0.00378	0.00471	0.00583

Table E.14. Values of M_{Max} for fixed head single short pile (3T) with varying 'EI' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	3.03E+09	55000	-248	-328	-385	-454
45%	2.45E+09	60500	-249	-329	-386	-454
40%	1.94E+09	66000	-251	-330	-387	-454
35%	1.48E+09	71500	-252	-331	-388	-454
30%	1.09E+09	77000	-258	-338	-396	-461
25%	7.56E+08	82500	-259	-339	-397	-461
20%	4.84E+08	88000	-260	-341	-398	-462
15%	2.72E+08	93500	-261	-342	-400	-463
10%	1.21E+08	99000	-262	-343	-400	-465
5%	3.03E+07	104500	-263	-344	-401	-466
0%	0.00E+00	110000	-264	-345	-402	-467
5%	3.03E+07	115500	-272	-354	-402	-476
10%	1.21E+08	121000	-273	-355	-404	-478
15%	2.72E+08	126500	-273	-356	-414	-479
20%	4.84E+08	132000	-274	-357	-416	-480
25%	7.56E+08	137500	-275	-358	-417	-481
30%	1.09E+09	143000	-276	-359	-418	-482
35%	1.48E+09	148500	-277	-359	-419	-484
40%	1.94E+09	154000	-283	-368	-428	-493
45%	2.45E+09	159500	-284	-369	-429	-495
50%	3.03E+09	165000	-285	-370	-430	-496

Table E.15(a) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'EI' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	3.61E-08	5.572%	8.70E-08	5.865%
10%	1.21E+08	5.52E-08	6.891%	1.30E-07	7.157%
15%	2.72E+08	7.56E-08	8.065%	1.81E-07	8.449%
20%	4.84E+08	1.02E-07	9.384%	2.45E-07	9.841%
25%	7.56E+08	1.33E-07	10.704%	3.25E-07	11.332%
30%	1.09E+09	1.72E-07	12.170%	4.16E-07	12.823%
35%	1.48E+09	5.78E-07	22.287%	1.45E-06	23.956%
40%	1.94E+09	9.12E-07	28.006%	2.12E-06	28.926%
45%	2.45E+09	1.05E-06	30.059%	2.46E-06	31.213%
50%	3.03E+09	1.21E-06	32.258%	2.87E-06	33.698%

Table E.15(b) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'EI' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	1.52E-07	6.171%	3.03E-07	6.858%
10%	1.21E+08	2.26E-07	7.516%	4.42E-07	8.292%
15%	2.72E+08	3.48E-07	9.335%	6.08E-07	9.726%
20%	4.84E+08	4.62E-07	10.759%	8.10E-07	11.222%
25%	7.56E+08	6.01E-07	12.263%	1.06E-06	12.843%
30%	1.09E+09	7.74E-07	13.924%	1.44E-06	14.963%
35%	1.48E+09	2.50E-06	25.000%	4.69E-06	26.995%
40%	1.94E+09	3.76E-06	30.696%	6.94E-06	32.855%
45%	2.45E+09	4.37E-06	33.070%	8.47E-06	36.284%
50%	3.03E+09	5.13E-06	35.839%	1.01E-05	39.713%

Table E.16(a) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'EI' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	20.25	1.705%	25	1.449%
10%	1.21E+08	30.25	2.083%	36	1.739%
15%	2.72E+08	36	2.273%	49	2.029%
20%	4.84E+08	49	2.652%	64	2.319%
25%	7.56E+08	64	3.030%	90.25	2.754%
30%	1.09E+09	81	3.409%	110.25	3.043%
35%	1.48E+09	156.25	4.735%	196	4.058%
40%	1.94E+09	256	6.061%	361	5.507%
45%	2.45E+09	306.25	6.629%	400	5.797%
50%	3.03E+09	342.25	7.008%	441	6.087%

Table E.16(b) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'EI' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	0.25	0.124%	25	1.071%
10%	1.21E+08	4	0.498%	42.25	1.392%
15%	2.72E+08	49	1.741%	64	1.713%
20%	4.84E+08	81	2.239%	81	1.927%
25%	7.56E+08	100	2.488%	100	2.141%
30%	1.09E+09	121	2.736%	110.25	2.248%
35%	1.48E+09	240.25	3.856%	225	3.212%
40%	1.94E+09	420.25	5.100%	380.25	4.176%
45%	2.45E+09	462.25	5.348%	420.25	4.390%
50%	3.03E+09	506.25	5.597%	441	4.497%

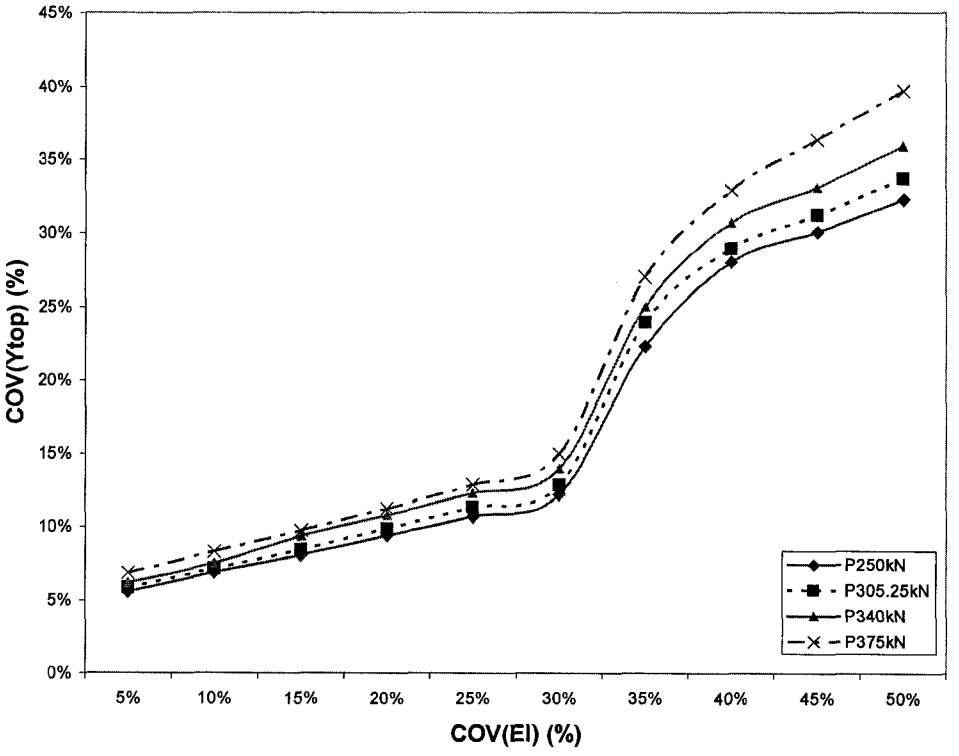

Fig. E.7 COV(Y_{Top}) for varying COV(EI) in fixed head short pile (3T).

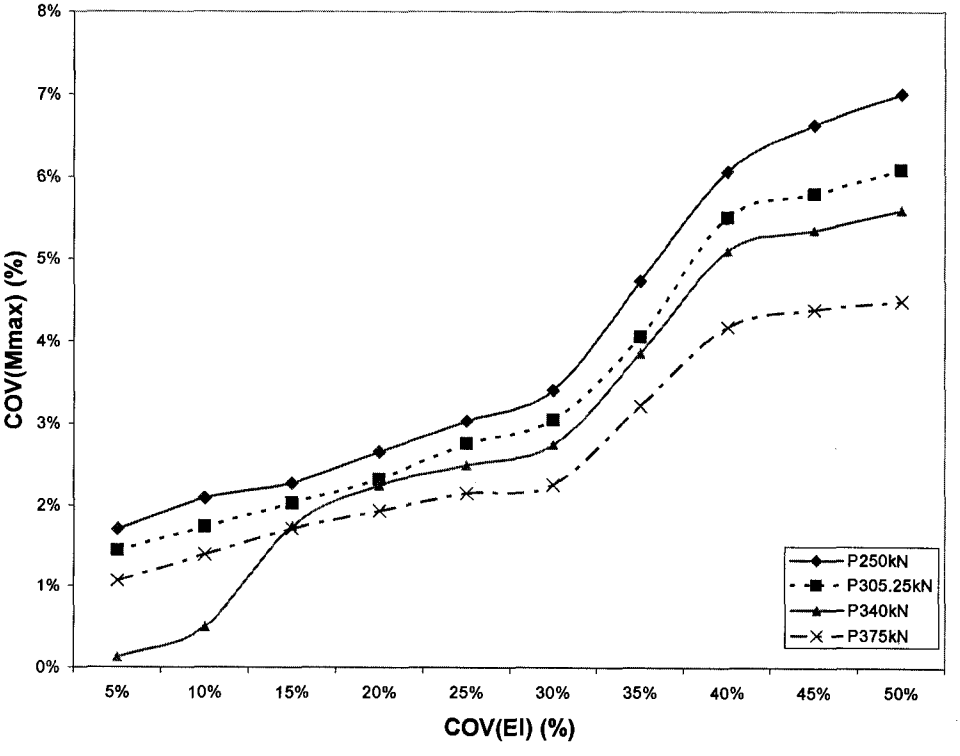

Fig. E.8 COV(M_{Max}) for varying COV(EI) in fixed head short pile (3T).

E.1.5 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'k' as varying random design variable

Table E.17 Values of Y_{Top} for fixed head single short pile (3T) with varying 'k' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	4.62E+09	68000	0.00353	0.00502	0.00635	0.00803
45%	3.75E+09	74800	0.0035	0.00505	0.00633	0.00802
40%	2.96E+09	81600	0.00347	0.00504	0.00632	0.00801
35%	2.27E+09	88400	0.00345	0.00502	0.00637	0.008
30%	1.66E+09	95200	0.00343	0.00501	0.00636	0.00799
25%	1.16E+09	102000	0.00341	0.00506	0.00635	0.00798
20%	7.40E+08	108800	0.00339	0.00505	0.00635	0.00797
15%	4.16E+08	115600	0.00344	0.00505	0.00634	0.00803
10%	1.85E+08	122400	0.00343	0.00504	0.00633	0.00803
5%	4.62E+07	129200	0.00342	0.00503	0.00633	0.00802
0%	0.00E+00	136000	0.00341	0.00503	0.00632	0.00802
5%	4.62E+07	142800	0.00341	0.00502	0.00632	0.00802
10%	1.85E+08	149600	0.0034	0.00502	0.00631	0.00801
15%	4.16E+08	156400	0.00339	0.00502	0.00631	0.00801
20%	7.40E+08	163200	0.00345	0.00501	0.00637	0.00801
25%	1.16E+09	170000	0.00344	0.00501	0.00637	0.008
30%	1.66E+09	176800	0.00344	0.005	0.00636	0.008
35%	2.27E+09	183600	0.00344	0.005	0.00636	0.008
40%	2.96E+09	190400	0.00344	0.00506	0.00636	0.00799
45%	3.75E+09	197200	0.00343	0.00505	0.00636	0.00799
50%	4.62E+09	204000	0.00343	0.00505	0.00635	0.00799

Table E.18. Values of M_{Max} for fixed head single short pile (3T) with varying 'k' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	4.62E+09	68000	-267	-345	-402	-467
45%	3.75E+09	74800	-266	-345	-402	-467
40%	2.96E+09	81600	-266	-345	-402	-467
35%	2.27E+09	88400	-265	-345	-403	-466
30%	1.66E+09	95200	-265	-344	-403	-466
25%	1.16E+09	102000	-264	-346	-403	-466
20%	7.40E+08	108800	-264	-345	-402	-466
15%	4.16E+08	115600	-264	-345	-402	-467
10%	1.85E+08	122400	-264	-345	-402	-467
5%	4.62E+07	129200	-264	-345	-402	-467
0%	0.00E+00	136000	-264	-345	-402	-467
5%	4.62E+07	142800	-264	-345	-402	-467
10%	1.85E+08	149600	-264	-345	-402	-467
15%	4.16E+08	156400	-264	-345	-402	-467
20%	7.40E+08	163200	-265	-345	-403	-467
25%	1.16E+09	170000	-265	-344	-403	-467
30%	1.66E+09	176800	-265	-344	-403	-467
35%	2.27E+09	183600	-265	-344	-403	-466
40%	2.96E+09	190400	-265	-346	-403	-466
45%	3.75E+09	197200	-264	-346	-403	-466
50%	4.62E+09	204000	-264	-346	-403	-466

Table E.19(a) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'k' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.50E-11	0.147%	2.50E-11	0.099%
10%	1.85E+08	2.25E-10	0.440%	1.00E-10	0.199%
15%	4.16E+08	6.25E-10	0.733%	2.25E-10	0.298%
20%	7.40E+08	9.00E-10	0.880%	4.00E-10	0.398%
25%	1.16E+09	2.25E-10	0.440%	6.25E-10	0.497%
30%	1.66E+09	2.50E-11	0.147%	2.50E-11	0.099%
35%	2.27E+09	2.50E-11	0.147%	1.00E-10	0.199%
40%	2.96E+09	2.25E-10	0.440%	1.00E-10	0.199%
45%	3.75E+09	1.23E-09	1.026%	0.00E+00	0.000%
50%	4.62E+09	2.50E-09	1.466%	2.25E-10	0.298%

Table E.19(b) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'k' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.50E-11	0.079%	0.00E+00	0.000%
10%	1.85E+08	1.00E-10	0.158%	1.00E-10	0.125%
15%	4.16E+08	2.25E-10	0.237%	1.00E-10	0.125%
20%	7.40E+08	1.00E-10	0.158%	4.00E-10	0.249%
25%	1.16E+09	1.00E-10	0.158%	1.00E-10	0.125%
30%	1.66E+09	0.00E+00	0.000%	2.50E-11	0.062%
35%	2.27E+09	2.50E-11	0.079%	0.00E+00	0.000%
40%	2.96E+09	4.00E-10	0.316%	1.00E-10	0.125%
45%	3.75E+09	2.25E-10	0.237%	2.25E-10	0.187%
50%	4.62E+09	0.00E+00	0.000%	4.00E-10	0.249%

Table E.20(a) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'k' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0	0.000%	0	0.000%
10%	1.85E+08	0	0.000%	0	0.000%
15%	4.16E+08	0	0.000%	0	0.000%
20%	7.40E+08	0.25	0.189%	0	0.000%
25%	1.16E+09	0.25	0.189%	1	0.290%
30%	1.66E+09	0	0.000%	0	0.000%
35%	2.27E+09	0	0.000%	0.25	0.145%
40%	2.96E+09	0.25	0.189%	0.25	0.145%
45%	3.75E+09	1	0.379%	0.25	0.145%
50%	4.62E+09	2.25	0.568%	0.25	0.145%

Table E.20(b) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'k' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0	0.000%	0	0.000%
10%	1.85E+08	0	0.000%	0	0.000%
15%	4.16E+08	0	0.000%	0	0.000%
20%	7.40E+08	0.25	0.124%	0.25	0.107%
25%	1.16E+09	0	0.000%	0.25	0.107%
30%	1.66E+09	0	0.000%	0.25	0.107%
35%	2.27E+09	0	0.000%	0	0.000%
40%	2.96E+09	0.25	0.124%	0.25	0.107%
45%	3.75E+09	0.25	0.124%	0.25	0.107%
50%	4.62E+09	0.25	0.124%	0.25	0.107%

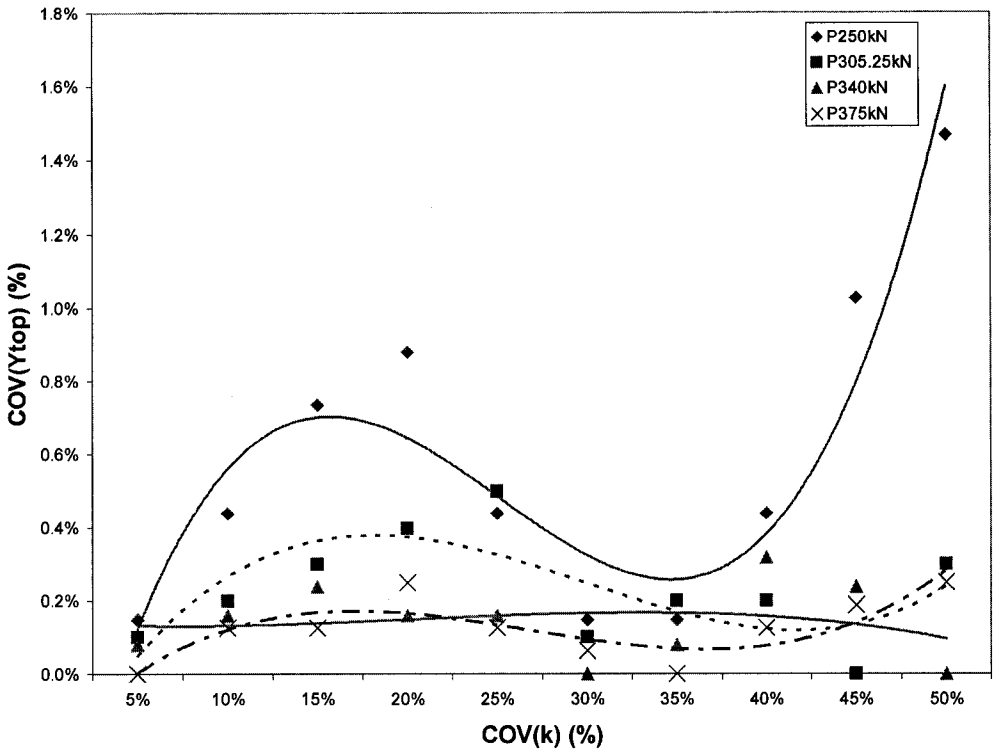

Fig. E.9 COV(Y_{Top}) for varying COV(k) in fixed head short pile (3T).

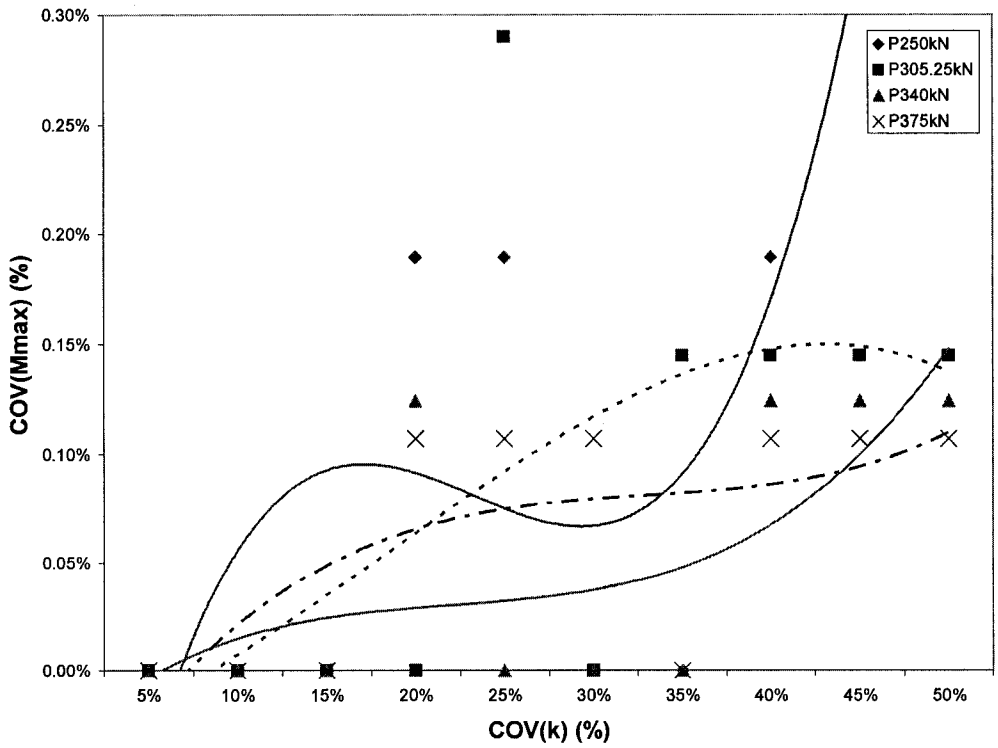

Fig. E.10 COV(M_{Max}) for varying COV(k) in fixed head short pile (3T).

E.1.6 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'γ'' as varying random design variable

Table E.21 Values of Y_{Top} for fixed head single short pile (3T) with varying 'γ'' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	8.7025	2.95	0.00343	0.00505	0.00635	0.00806
45%	7.049025	3.245	0.00342	0.00505	0.00635	0.00806
40%	5.5696	3.54	0.00342	0.00505	0.00635	0.00805
35%	4.264225	3.835	0.00342	0.00504	0.00634	0.00805
30%	3.1329	4.13	0.00342	0.00504	0.00634	0.00804
25%	2.175625	4.425	0.00342	0.00504	0.00634	0.00804
20%	1.3924	4.72	0.00342	0.00504	0.00633	0.00804
15%	0.783225	5.015	0.00342	0.00504	0.00633	0.00803
10%	0.3481	5.31	0.00342	0.00503	0.00633	0.00803
5%	0.087025	5.605	0.00341	0.00503	0.00633	0.00802
0%	0	5.9	0.00341	0.00503	0.00632	0.00802
5%	0.087025	6.195	0.00341	0.00503	0.00632	0.00802
10%	0.3481	6.49	0.00341	0.00502	0.00632	0.00801
15%	0.783225	6.785	0.00341	0.00502	0.00631	0.00801
20%	1.3924	7.08	0.00341	0.00502	0.00631	0.008
25%	2.175625	7.375	0.00341	0.00502	0.00631	0.008
30%	3.1329	7.67	0.00341	0.00502	0.00631	0.008
35%	4.264225	7.965	0.0034	0.00501	0.0063	0.00799
40%	5.5696	8.26	0.0034	0.00501	0.0063	0.00799
45%	7.049025	8.555	0.0034	0.00501	0.0063	0.00798
50%	8.7025	8.85	0.0034	0.00501	0.0063	0.00798

Table E.22. Values of M_{Max} for fixed head single short pile (3T) with varying 'γ' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	8.7025	2.95	-264	-346	-403	-468
45%	7.049025	3.245	-264	-345	-403	-468
40%	5.5696	3.54	-264	-345	-402	-468
35%	4.264225	3.835	-264	-345	-402	-468
30%	3.1329	4.13	-264	-345	-402	-467
25%	2.175625	4.425	-264	-345	-402	-467
20%	1.3924	4.72	-264	-345	-402	-467
15%	0.783225	5.015	-264	-345	-402	-467
10%	0.3481	5.31	-264	-345	-402	-467
5%	0.087025	5.605	-264	-345	-402	-467
0%	0	5.9	-264	-345	-402	-467
5%	0.087025	6.195	-264	-345	-402	-467
10%	0.3481	6.49	-264	-345	-402	-467
15%	0.783225	6.785	-264	-345	-402	-467
20%	1.3924	7.08	-264	-345	-402	-467
25%	2.175625	7.375	-264	-345	-401	-466
30%	3.1329	7.67	-264	-345	-401	-466
35%	4.264225	7.965	-264	-345	-401	-466
40%	5.5696	8.26	-264	-345	-401	-466
45%	7.049025	8.555	-264	-345	-401	-466
50%	8.7025	8.85	-264	-345	-401	-466

Table E.23(a) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'γ'' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	0.00E+00	0.000%
10%	3.48E-01	2.50E-11	0.147%	2.50E-11	0.099%
15%	7.83E-01	2.50E-11	0.147%	1.00E-10	0.199%
20%	1.39E+00	2.50E-11	0.147%	1.00E-10	0.199%
25%	2.18E+00	2.50E-11	0.147%	1.00E-10	0.199%
30%	3.13E+00	2.50E-11	0.147%	1.00E-10	0.199%
35%	4.26E+00	1.00E-10	0.293%	2.25E-10	0.298%
40%	5.57E+00	1.00E-10	0.293%	4.00E-10	0.398%
45%	7.05E+00	1.00E-10	0.293%	4.00E-10	0.398%
50%	8.70E+00	2.25E-10	0.440%	4.00E-10	0.398%

Table E.23(b) Value of COV(Y_{Top}) for fixed head single short pile (3T) with varying 'γ'' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	2.50E-11	0.079%	0.00E+00	0.000%
10%	3.48E-01	2.50E-11	0.079%	1.00E-10	0.125%
15%	7.83E-01	1.00E-10	0.158%	1.00E-10	0.125%
20%	1.39E+00	1.00E-10	0.158%	4.00E-10	0.249%
25%	2.18E+00	2.25E-10	0.237%	4.00E-10	0.249%
30%	3.13E+00	2.25E-10	0.237%	4.00E-10	0.249%
35%	4.26E+00	4.00E-10	0.316%	9.00E-10	0.374%
40%	5.57E+00	6.25E-10	0.396%	9.00E-10	0.374%
45%	7.05E+00	6.25E-10	0.396%	1.60E-09	0.499%
50%	8.70E+00	6.25E-10	0.396%	1.60E-09	0.499%

Table E.24(a) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'γ' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	8.70E-02	0	0.000%	0	0.000%
10%	3.48E-01	0	0.000%	0	0.000%
15%	7.83E-01	0	0.000%	0	0.000%
20%	1.39E+00	0	0.000%	0	0.000%
25%	2.18E+00	0	0.000%	0	0.000%
30%	3.13E+00	0	0.000%	0	0.000%
35%	4.26E+00	0	0.000%	0	0.000%
40%	5.57E+00	0	0.000%	0	0.000%
45%	7.05E+00	0	0.000%	0	0.000%
50%	8.70E+00	0	0.000%	0.25	0.145%

Table E.24(b) Value of COV(M_{Max}) for fixed head single short pile (3T) with varying 'γ' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	8.70E-02	0	0.000%	0	0.000%
10%	3.48E-01	0	0.000%	0	0.000%
15%	7.83E-01	0	0.000%	0	0.000%
20%	1.39E+00	0	0.000%	0	0.000%
25%	2.18E+00	0.25	0.124%	0.25	0.107%
30%	3.13E+00	0.25	0.124%	0.25	0.107%
35%	4.26E+00	0.25	0.124%	1	0.214%
40%	5.57E+00	0.25	0.124%	1	0.214%
45%	7.05E+00	1	0.249%	1	0.214%
50%	8.70E+00	1	0.249%	1	0.214%

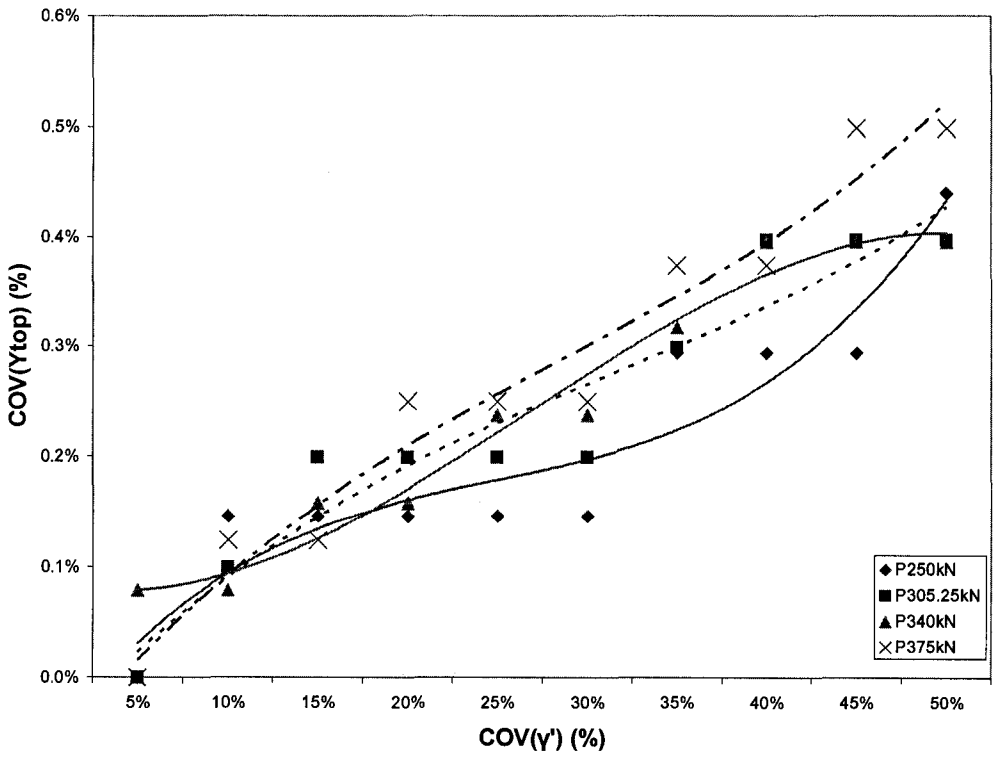

Fig. E.11 COV(Y_{Top}) for varying COV(γ') in fixed head short pile (3T).

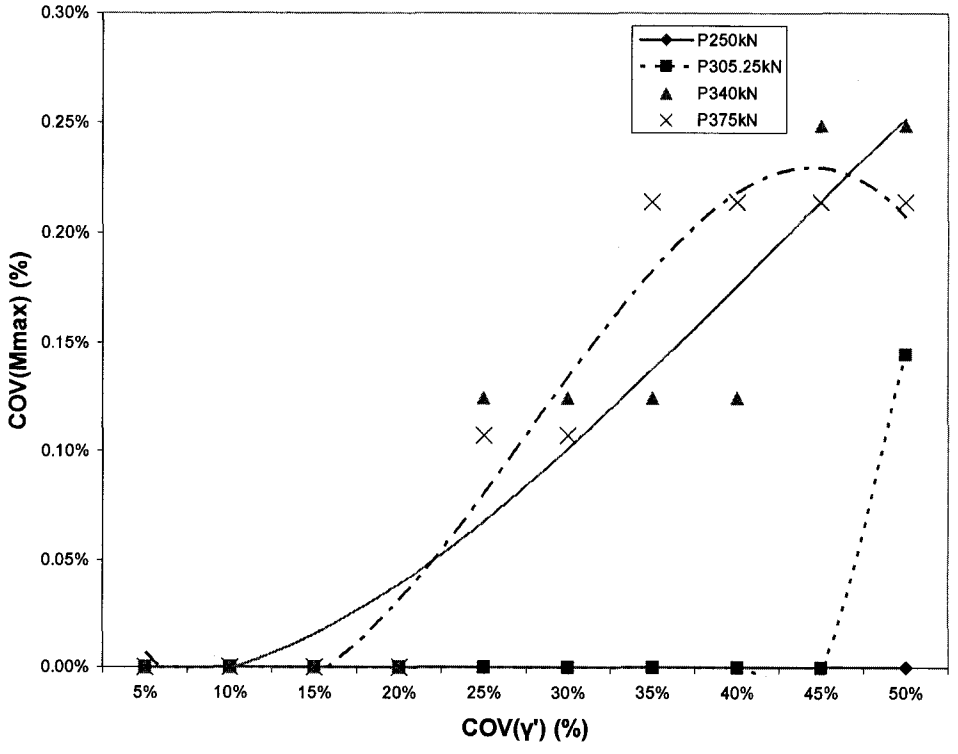

Fig. E.12 COV(M_{Max}) for varying COV(γ') in fixed head short pile (3T).

E.2 Reliability analysis of fixed head single short pile

E.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 250 kN

$g(Y_{top})^o = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00959$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06\ m^2$

Table E.25 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 250 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.25E-10	6.76E-06	3.69	6.50E-08	6.83E-06	3.67
10%	6.76E-06	1.23E-09	6.76E-06	3.69	2.03E-07	6.96E-06	3.63
15%	6.76E-06	8.10E-09	6.77E-06	3.69	4.69E-07	7.23E-06	3.57
20%	6.76E-06	1.44E-08	6.77E-06	3.68	8.65E-07	7.62E-06	3.47
25%	6.76E-06	2.56E-08	6.79E-06	3.68	1.53E-06	8.29E-06	3.33
30%	6.76E-06	5.76E-08	6.82E-06	3.67	2.43E-06	9.19E-06	3.16
35%	6.76E-06	1.19E-07	6.88E-06	3.66	4.04E-06	1.08E-05	2.92
40%	6.76E-06	2.30E-07	6.99E-06	3.63	6.63E-06	1.34E-05	2.62
45%	6.76E-06	4.10E-07	7.17E-06	3.58	1.13E-05	1.81E-05	2.26
50%	6.76E-06	9.60E-07	7.72E-06	3.45	2.03E-05	2.71E-05	1.84

Table E.26 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 250 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	5.62E-09	6.77E-06	3.69	3.61E-08	6.80E-06	3.68
10%	6.76E-06	2.25E-08	6.78E-06	3.68	5.52E-08	6.82E-06	3.67
15%	6.76E-06	8.12E-08	6.84E-06	3.67	7.56E-08	6.84E-06	3.67
20%	6.76E-06	1.30E-07	6.89E-06	3.65	1.02E-07	6.86E-06	3.66
25%	6.76E-06	1.94E-07	6.95E-06	3.64	1.33E-07	6.89E-06	3.65
30%	6.76E-06	2.60E-07	7.02E-06	3.62	1.72E-07	6.93E-06	3.64
35%	6.76E-06	3.42E-07	7.10E-06	3.60	5.78E-07	7.34E-06	3.54
40%	6.76E-06	4.36E-07	7.20E-06	3.58	9.12E-07	7.67E-06	3.46
45%	6.76E-06	5.40E-07	7.30E-06	3.55	1.05E-06	7.81E-06	3.43
50%	6.76E-06	6.48E-07	7.41E-06	3.52	1.21E-06	7.97E-06	3.40

Table E.27 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 250 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.69	2.50E-11	6.76E-06	3.69
10%	6.76E-06	2.50E-11	6.76E-06	3.69	2.25E-10	6.76E-06	3.69
15%	6.76E-06	2.50E-11	6.76E-06	3.69	6.25E-10	6.76E-06	3.69
20%	6.76E-06	2.50E-11	6.76E-06	3.69	9.00E-10	6.76E-06	3.69
25%	6.76E-06	2.50E-11	6.76E-06	3.69	2.25E-10	6.76E-06	3.69
30%	6.76E-06	2.50E-11	6.76E-06	3.69	2.50E-11	6.76E-06	3.69
35%	6.76E-06	1.00E-10	6.76E-06	3.69	2.50E-11	6.76E-06	3.69
40%	6.76E-06	1.00E-10	6.76E-06	3.69	2.25E-10	6.76E-06	3.69
45%	6.76E-06	1.00E-10	6.76E-06	3.69	1.23E-09	6.76E-06	3.69
50%	6.76E-06	2.25E-10	6.76E-06	3.69	2.50E-09	6.76E-06	3.69

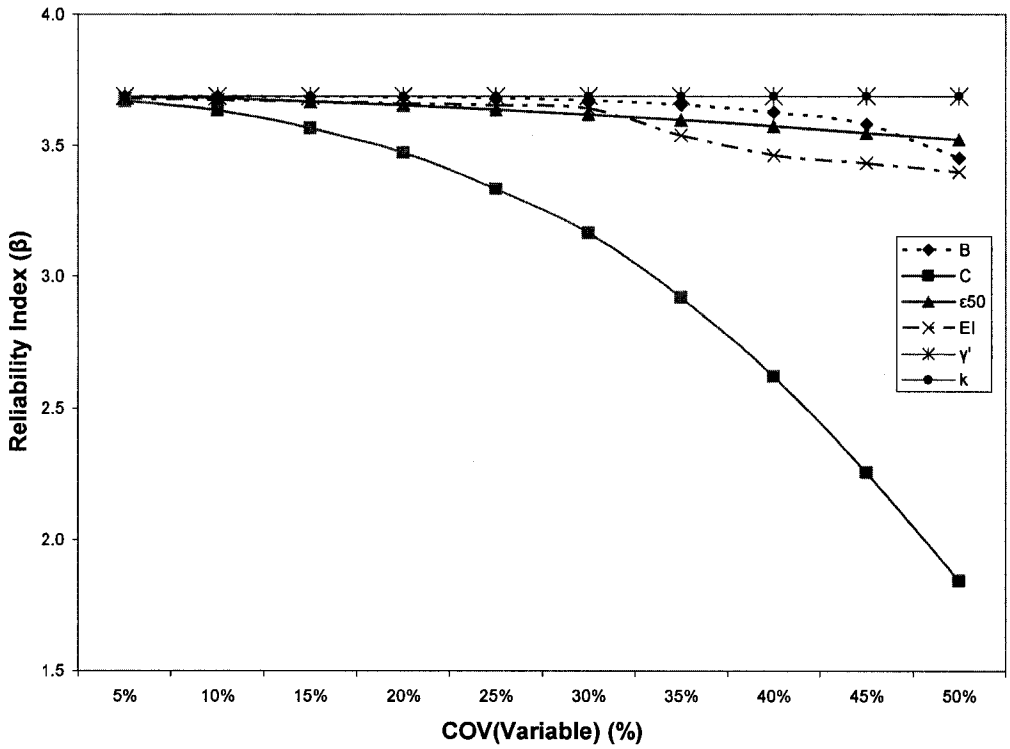

Fig. E.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single short pile (3T) at 250 kN lateral load.

For lateral load 305.25 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00797 \text{ m}$$

Table E.28 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 305.25 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	4.23E-09	6.76E-06	3.06	1.41E-07	6.90E-06	3.03
10%	6.76E-06	2.56E-08	6.79E-06	3.06	5.85E-07	7.35E-06	2.94
15%	6.76E-06	5.76E-08	6.82E-06	3.05	1.40E-06	8.16E-06	2.79
20%	6.76E-06	1.12E-07	6.87E-06	3.04	2.86E-06	9.62E-06	2.57
25%	6.76E-06	2.65E-07	7.03E-06	3.01	5.11E-06	1.19E-05	2.31
30%	6.76E-06	4.62E-07	7.22E-06	2.97	9.00E-06	1.58E-05	2.01
35%	6.76E-06	1.00E-06	7.76E-06	2.86	1.60E-05	2.27E-05	1.67
40%	6.76E-06	2.34E-06	9.10E-06	2.64	3.31E-05	3.98E-05	1.26
45%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table E.29 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 305.25 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.21E-08	6.77E-06	3.06	8.70E-08	6.85E-06	3.05
10%	6.76E-06	4.84E-08	6.81E-06	3.05	1.30E-07	6.89E-06	3.04
15%	6.76E-06	1.06E-07	6.87E-06	3.04	1.81E-07	6.94E-06	3.03
20%	6.76E-06	1.89E-07	6.95E-06	3.02	2.45E-07	7.01E-06	3.01
25%	6.76E-06	2.97E-07	7.06E-06	3.00	3.25E-07	7.08E-06	2.99
30%	6.76E-06	4.69E-07	7.23E-06	2.96	4.16E-07	7.18E-06	2.98
35%	6.76E-06	6.72E-07	7.43E-06	2.92	1.45E-06	8.21E-06	2.78
40%	6.76E-06	8.65E-07	7.62E-06	2.89	2.12E-06	8.88E-06	2.68
45%	6.76E-06	1.06E-06	7.82E-06	2.85	2.46E-06	9.22E-06	2.62
50%	6.76E-06	1.30E-06	8.06E-06	2.81	2.87E-06	9.63E-06	2.57

Table E.30 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 305.25 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.07	2.50E-11	6.76E-06	3.07
10%	6.76E-06	2.50E-11	6.76E-06	3.07	1.00E-10	6.76E-06	3.07
15%	6.76E-06	1.00E-10	6.76E-06	3.07	2.25E-10	6.76E-06	3.07
20%	6.76E-06	1.00E-10	6.76E-06	3.07	4.00E-10	6.76E-06	3.07
25%	6.76E-06	1.00E-10	6.76E-06	3.07	6.25E-10	6.76E-06	3.07
30%	6.76E-06	1.00E-10	6.76E-06	3.07	2.50E-11	6.76E-06	3.07
35%	6.76E-06	2.25E-10	6.76E-06	3.07	1.00E-10	6.76E-06	3.07
40%	6.76E-06	4.00E-10	6.76E-06	3.07	1.00E-10	6.76E-06	3.07
45%	6.76E-06	4.00E-10	6.76E-06	3.07	0.00E+00	6.76E-06	3.07
50%	6.76E-06	4.00E-10	6.76E-06	3.07	2.25E-10	6.76E-06	3.07

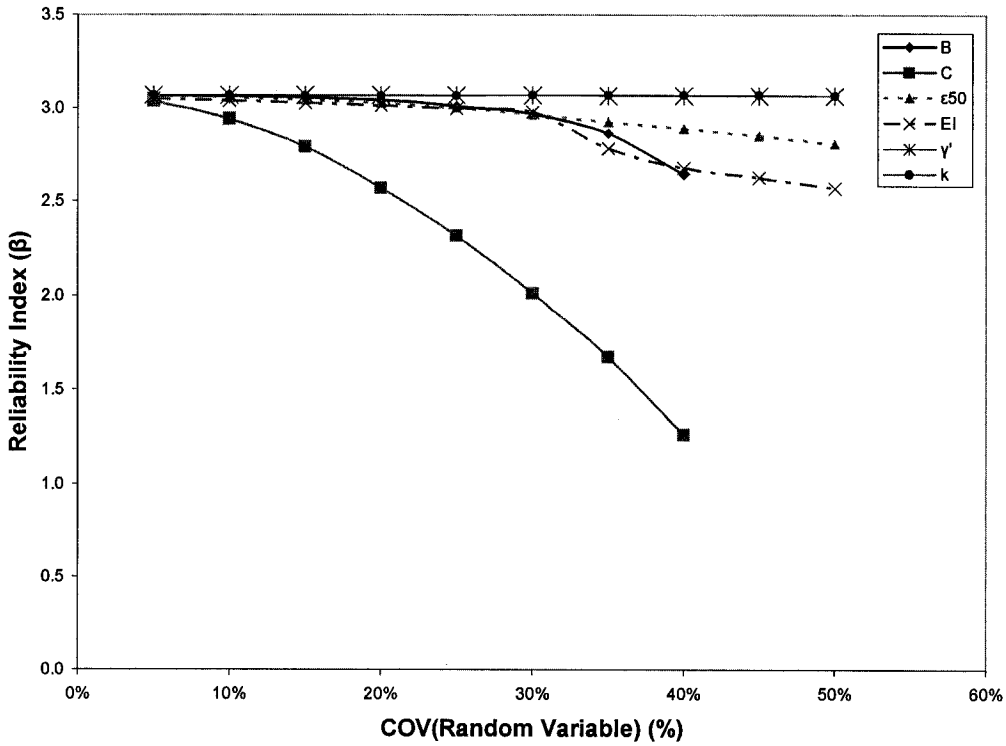

Fig. E.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single short pile (3T) at 305.25 kN lateral load.

For lateral load 340 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00668 \text{ m}$$

Table E.31 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 340 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	2.25E-08	6.78E-06	2.56	2.70E-07	7.03E-06	2.52
10%	6.76E-06	7.56E-08	6.84E-06	2.55	1.21E-06	7.97E-06	2.37
15%	6.76E-06	1.76E-07	6.94E-06	2.54	2.92E-06	9.68E-06	2.15
20%	6.76E-06	4.10E-07	7.17E-06	2.49	6.05E-06	1.28E-05	1.87
25%	6.76E-06	9.22E-07	7.68E-06	2.41	1.17E-05	1.84E-05	1.56
30%	6.76E-06	2.06E-06	8.82E-06	2.25	2.40E-05	3.08E-05	1.20
35%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
40%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
45%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table E.32 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 340 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.69E-08	6.78E-06	2.57	1.52E-07	6.91E-06	2.54
10%	6.76E-06	6.76E-08	6.83E-06	2.56	2.26E-07	6.99E-06	2.53
15%	6.76E-06	1.52E-07	6.91E-06	2.54	3.48E-07	7.11E-06	2.51
20%	6.76E-06	2.76E-07	7.04E-06	2.52	4.62E-07	7.22E-06	2.49
25%	6.76E-06	4.69E-07	7.23E-06	2.48	6.01E-07	7.36E-06	2.46
30%	6.76E-06	6.72E-07	7.43E-06	2.45	7.74E-07	7.53E-06	2.43
35%	6.76E-06	8.93E-07	7.65E-06	2.41	2.50E-06	9.26E-06	2.20
40%	6.76E-06	1.16E-06	7.92E-06	2.37	3.76E-06	1.05E-05	2.06
45%	6.76E-06	1.43E-06	8.19E-06	2.33	4.37E-06	1.11E-05	2.00
50%	6.76E-06	1.74E-06	8.50E-06	2.29	5.13E-06	1.19E-05	1.94

Table E.33 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 340 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	2.57	2.50E-11	6.76E-06	2.57
10%	6.76E-06	2.50E-11	6.76E-06	2.57	1.00E-10	6.76E-06	2.57
15%	6.76E-06	1.00E-10	6.76E-06	2.57	2.25E-10	6.76E-06	2.57
20%	6.76E-06	1.00E-10	6.76E-06	2.57	1.00E-10	6.76E-06	2.57
25%	6.76E-06	2.25E-10	6.76E-06	2.57	1.00E-10	6.76E-06	2.57
30%	6.76E-06	2.25E-10	6.76E-06	2.57	0.00E+00	6.76E-06	2.57
35%	6.76E-06	4.00E-10	6.76E-06	2.57	2.50E-11	6.76E-06	2.57
40%	6.76E-06	6.25E-10	6.76E-06	2.57	4.00E-10	6.76E-06	2.57
45%	6.76E-06	6.25E-10	6.76E-06	2.57	2.25E-10	6.76E-06	2.57
50%	6.76E-06	6.25E-10	6.76E-06	2.57	0.00E+00	6.76E-06	2.57

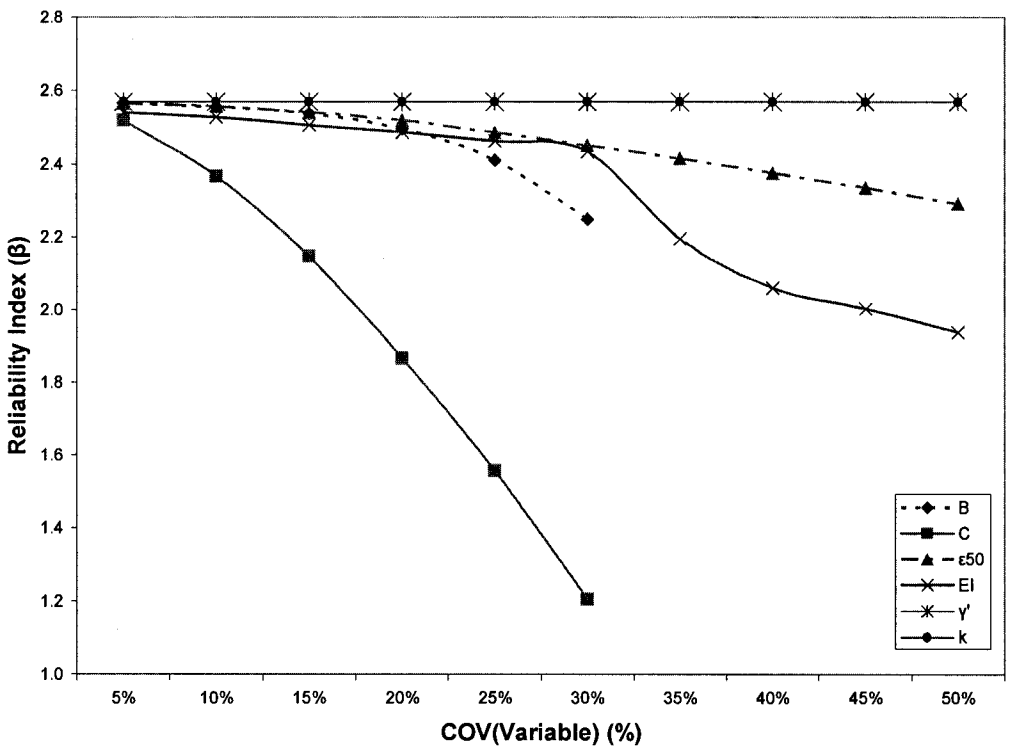

Fig. E.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single short pile (3T) at 340 kN lateral load.

For lateral load 375 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00498 \text{ m}$$

Table E.34 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 375 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	6.00E-08	6.82E-06	1.91	6.08E-07	7.37E-06	1.83
10%	6.76E-06	2.65E-07	7.03E-06	1.88	2.62E-06	9.38E-06	1.63
15%	6.76E-06	7.14E-07	7.47E-06	1.82	6.76E-06	1.35E-05	1.35
20%	6.76E-06	1.78E-06	8.54E-06	1.70	1.57E-05	2.25E-05	1.05
25%	6.76E-06	5.88E-06	1.26E-05	1.40	1.12E-03	1.12E-03	0.15
30%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
35%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
40%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
45%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table E.35 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 375 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	5.62E-09	6.77E-06	1.91	3.03E-07	7.06E-06	1.87
10%	6.76E-06	9.61E-08	6.86E-06	1.90	4.42E-07	7.20E-06	1.86
15%	6.76E-06	2.12E-07	6.97E-06	1.89	6.08E-07	7.37E-06	1.83
20%	6.76E-06	3.72E-07	7.13E-06	1.86	8.10E-07	7.57E-06	1.81
25%	6.76E-06	5.78E-07	7.34E-06	1.84	1.06E-06	7.82E-06	1.78
30%	6.76E-06	8.19E-07	7.58E-06	1.81	1.44E-06	8.20E-06	1.74
35%	6.76E-06	1.10E-06	7.86E-06	1.78	4.69E-06	1.14E-05	1.47
40%	6.76E-06	1.42E-06	8.18E-06	1.74	6.94E-06	1.37E-05	1.35
45%	6.76E-06	1.74E-06	8.50E-06	1.71	8.47E-06	1.52E-05	1.28
50%	6.76E-06	2.07E-06	8.83E-06	1.68	1.01E-05	1.69E-05	1.21

Table E.36 Reliability Index connected to Y_{Top} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 375 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	1.92	0.00E+00	6.76E-06	1.92
10%	6.76E-06	1.00E-10	6.76E-06	1.92	1.00E-10	6.76E-06	1.92
15%	6.76E-06	1.00E-10	6.76E-06	1.92	1.00E-10	6.76E-06	1.92
20%	6.76E-06	4.00E-10	6.76E-06	1.92	4.00E-10	6.76E-06	1.92
25%	6.76E-06	4.00E-10	6.76E-06	1.92	1.00E-10	6.76E-06	1.92
30%	6.76E-06	4.00E-10	6.76E-06	1.92	2.50E-11	6.76E-06	1.92
35%	6.76E-06	9.00E-10	6.76E-06	1.92	0.00E+00	6.76E-06	1.92
40%	6.76E-06	9.00E-10	6.76E-06	1.92	1.00E-10	6.76E-06	1.92
45%	6.76E-06	1.60E-09	6.76E-06	1.92	2.25E-10	6.76E-06	1.92
50%	6.76E-06	1.60E-09	6.76E-06	1.92	4.00E-10	6.76E-06	1.92

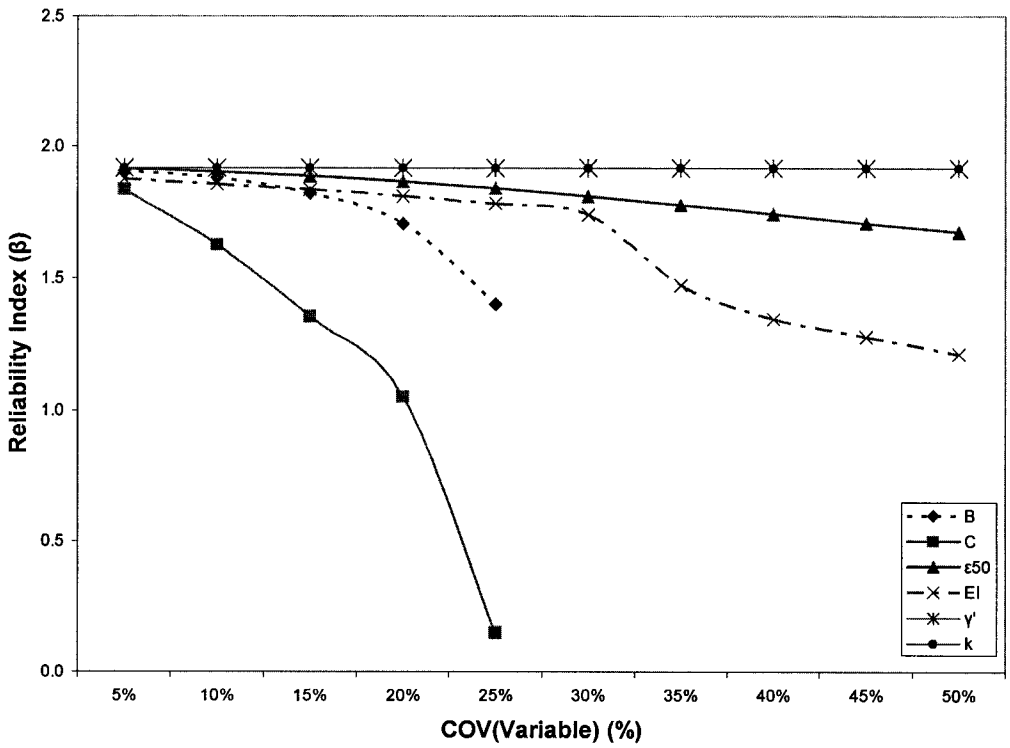

Fig. E.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single short pile (3T) at 375 kN lateral load.

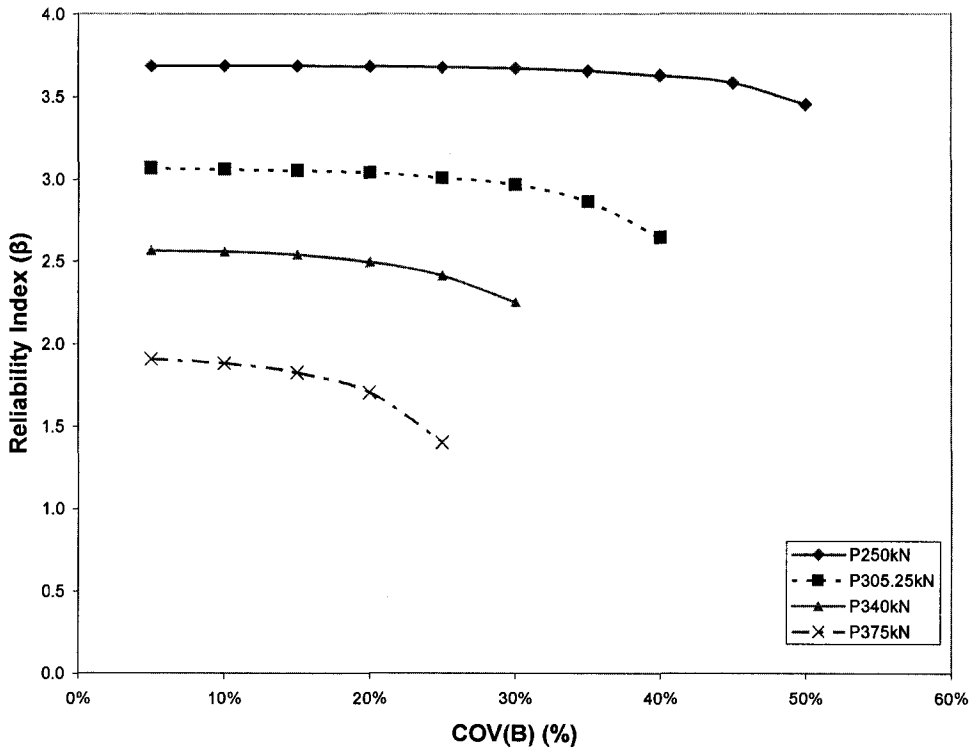

Fig. E.17 Reliability Index related to Y_{Top} for fixed head short pile with varying 'B'.

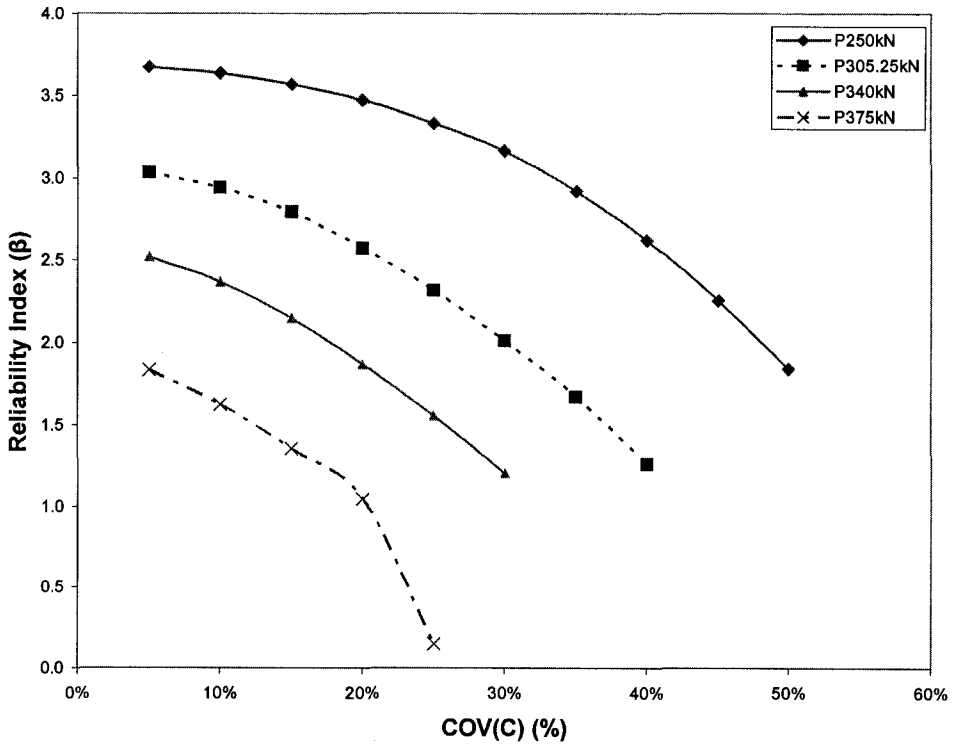

Fig. E.18 Reliability Index related to Y_{Top} for fixed head short pile with varying 'C'.

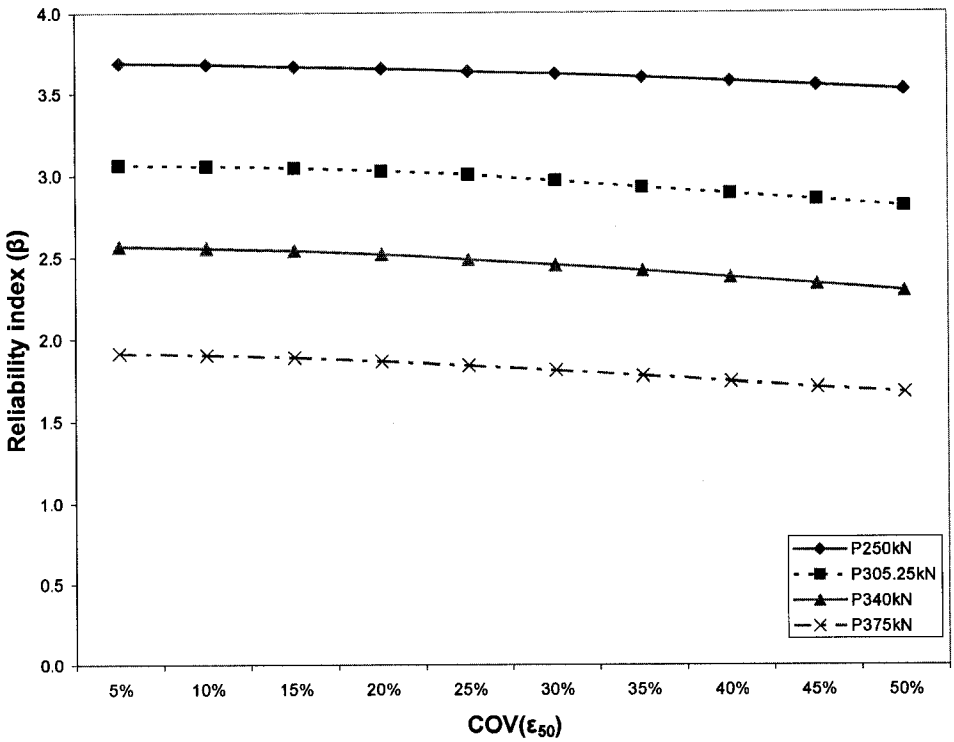

Fig. E.19 Reliability Index related to Y_{Top} for fixed head short pile with varying 'ε_{50}'.

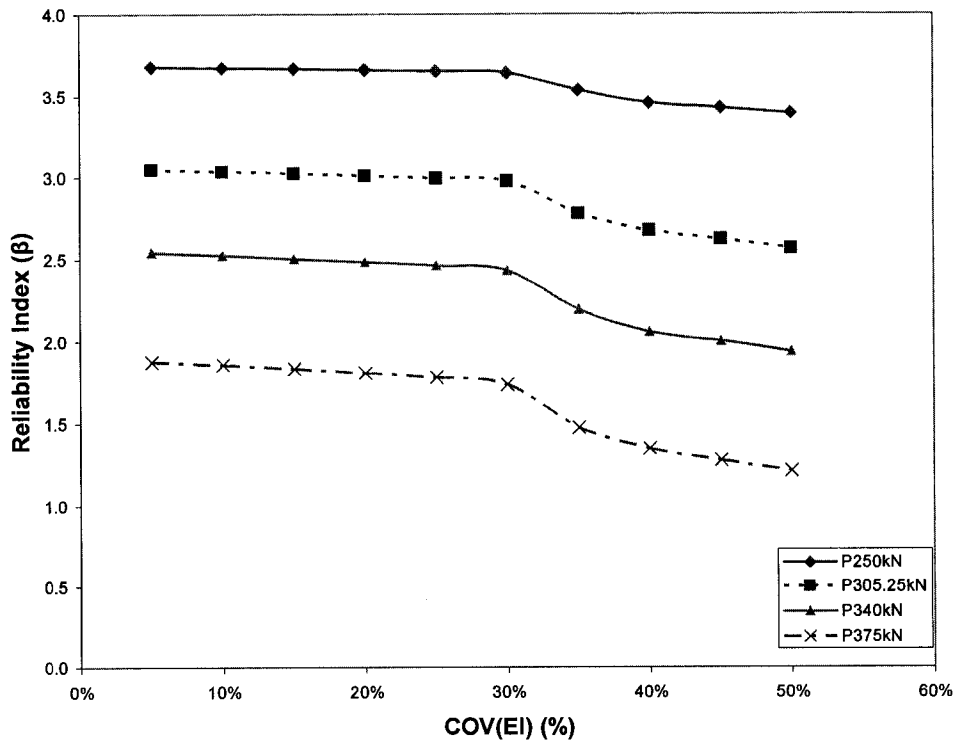

Fig. E.20 Reliability Index related to Y_{Top} for fixed head short pile with varying 'EI'.

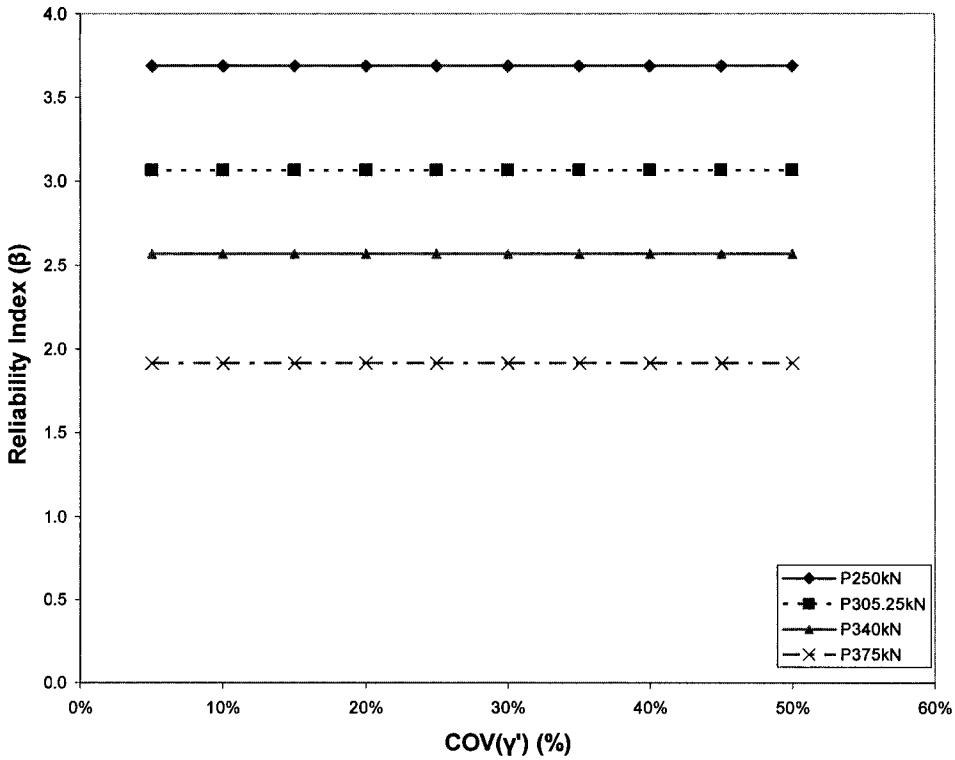

Fig. E.21 Reliability Index related to Y_{Top} for fixed head short pile with varying 'γ''.

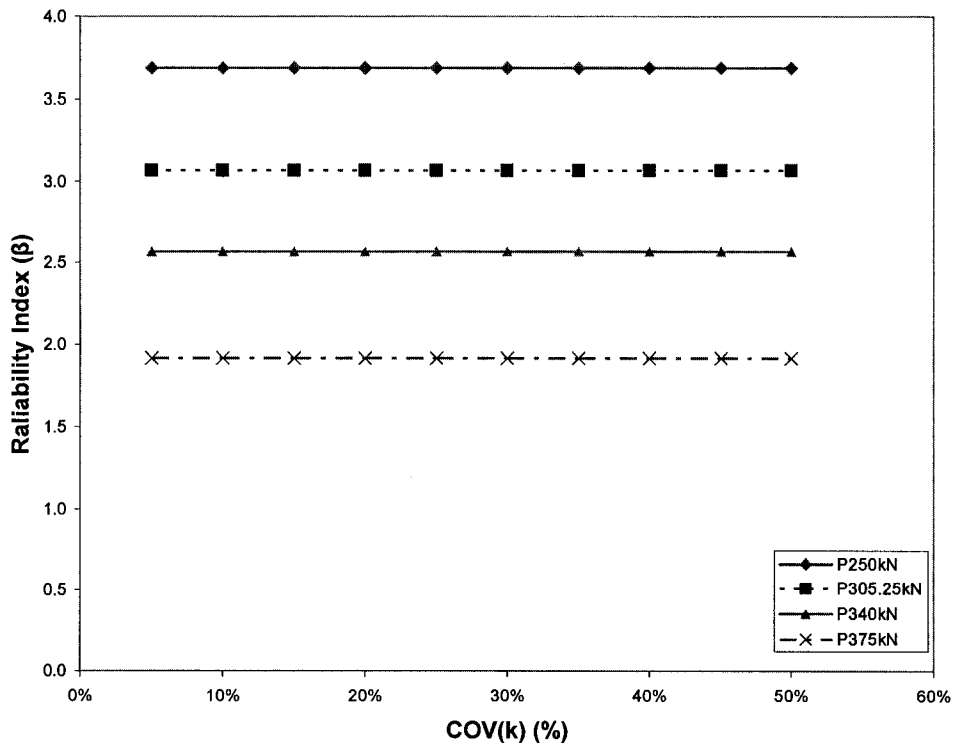

Fig. E.22 Reliability Index related to Y_{Top} for fixed head short pile with varying 'k'.

E.2.1 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 250 kN

$$g(M_{Max})^o = M_{Max}^{Resisto} - M_{Max}^{Currento} = 630 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table E.37 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 250 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.52	36	32005.44	3.52
10%	31969.44	0.25	31969.69	3.52	121	32090.44	3.52
15%	31969.44	2.25	31971.69	3.52	272.25	32241.69	3.51
20%	31969.44	4	31973.44	3.52	484	32453.44	3.50
25%	31969.44	6.25	31975.69	3.52	841	32810.44	3.48
30%	31969.44	16	31985.44	3.52	1296	33265.44	3.45
35%	31969.44	36	32005.44	3.52	2025	33994.44	3.42
40%	31969.44	81	32050.44	3.52	3136	35105.44	3.36
45%	31969.44	144	32113.44	3.52	4900	36869.44	3.28
50%	31969.44	342.25	32311.69	3.50	7832.25	39801.69	3.16

Table E.38 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 250 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	4	31973.44	3.52	20.25	31989.69	3.52
10%	31969.44	9	31978.44	3.52	30.25	31999.69	3.52
15%	31969.44	36	32005.44	3.52	36	32005.44	3.52
20%	31969.44	56.25	32025.69	3.52	49	32018.44	3.52
25%	31969.44	90.25	32059.69	3.52	64	32033.44	3.52
30%	31969.44	110.25	32079.69	3.52	81	32050.44	3.52
35%	31969.44	156.25	32125.69	3.51	156.25	32125.69	3.51
40%	31969.44	196	32165.44	3.51	256	32225.44	3.51
45%	31969.44	256	32225.44	3.51	306.25	32275.69	3.51
50%	31969.44	289	32258.44	3.51	342.25	32311.69	3.50

Table E.39 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 250 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.52	0	31969.44	3.52
10%	31969.44	0	31969.44	3.52	0	31969.44	3.52
15%	31969.44	0	31969.44	3.52	0	31969.44	3.52
20%	31969.44	0	31969.44	3.52	0.25	31969.69	3.52
25%	31969.44	0	31969.44	3.52	0.25	31969.69	3.52
30%	31969.44	0	31969.44	3.52	0	31969.44	3.52
35%	31969.44	0	31969.44	3.52	0	31969.44	3.52
40%	31969.44	0	31969.44	3.52	0.25	31969.69	3.52
45%	31969.44	0	31969.44	3.52	1	31970.44	3.52
50%	31969.44	0	31969.44	3.52	2.25	31971.69	3.52

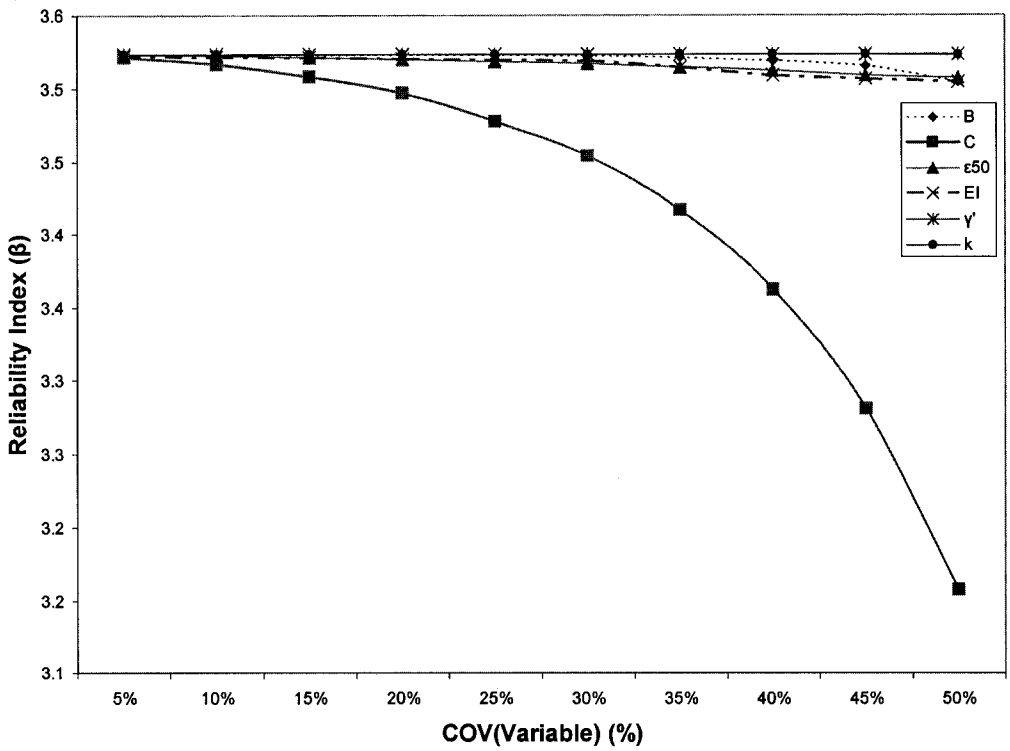

Fig. E.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single short pile (3T) at 250 kN lateral load.

For lateral load 305.25 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 549 \text{ kN.m}$$

Table E.40 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 305.25 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1	31970.44	3.07	72.25	32041.69	3.07
10%	31969.44	9	31978.44	3.07	306.25	32275.69	3.06
15%	31969.44	25	31994.44	3.07	702.25	32671.69	3.04
20%	31969.44	42.25	32011.69	3.07	1406.25	33375.69	3.01
25%	31969.44	100	32069.44	3.07	2401	34370.44	2.96
30%	31969.44	169	32138.44	3.06	3969	35938.44	2.90
35%	31969.44	380.25	32349.69	3.05	6480.25	38449.69	2.80
40%	31969.44	870.25	32839.69	3.03	11772.25	43741.69	2.62
45%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table E.41 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 305.25 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	4	31973.44	3.07	25	31994.44	3.07
10%	31969.44	16	31985.44	3.07	36	32005.44	3.07
15%	31969.44	36	32005.44	3.07	49	32018.44	3.07
20%	31969.44	64	32033.44	3.07	64	32033.44	3.07
25%	31969.44	90.25	32059.69	3.07	90.25	32059.69	3.07
30%	31969.44	144	32113.44	3.06	110.25	32079.69	3.07
35%	31969.44	210.25	32179.69	3.06	196	32165.44	3.06
40%	31969.44	272.25	32241.69	3.06	361	32330.44	3.05
45%	31969.44	342.25	32311.69	3.05	400	32369.44	3.05
50%	31969.44	420.25	32389.69	3.05	441	32410.44	3.05

Table E.42 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 305.25 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.07	0	31969.44	3.07
10%	31969.44	0	31969.44	3.07	0	31969.44	3.07
15%	31969.44	0	31969.44	3.07	0	31969.44	3.07
20%	31969.44	0	31969.44	3.07	0	31969.44	3.07
25%	31969.44	0	31969.44	3.07	1	31970.44	3.07
30%	31969.44	0	31969.44	3.07	0	31969.44	3.07
35%	31969.44	0	31969.44	3.07	0.25	31969.69	3.07
40%	31969.44	0	31969.44	3.07	0.25	31969.69	3.07
45%	31969.44	0	31969.44	3.07	0.25	31969.69	3.07
50%	31969.44	0.25	31969.69	3.07	0.25	31969.69	3.07

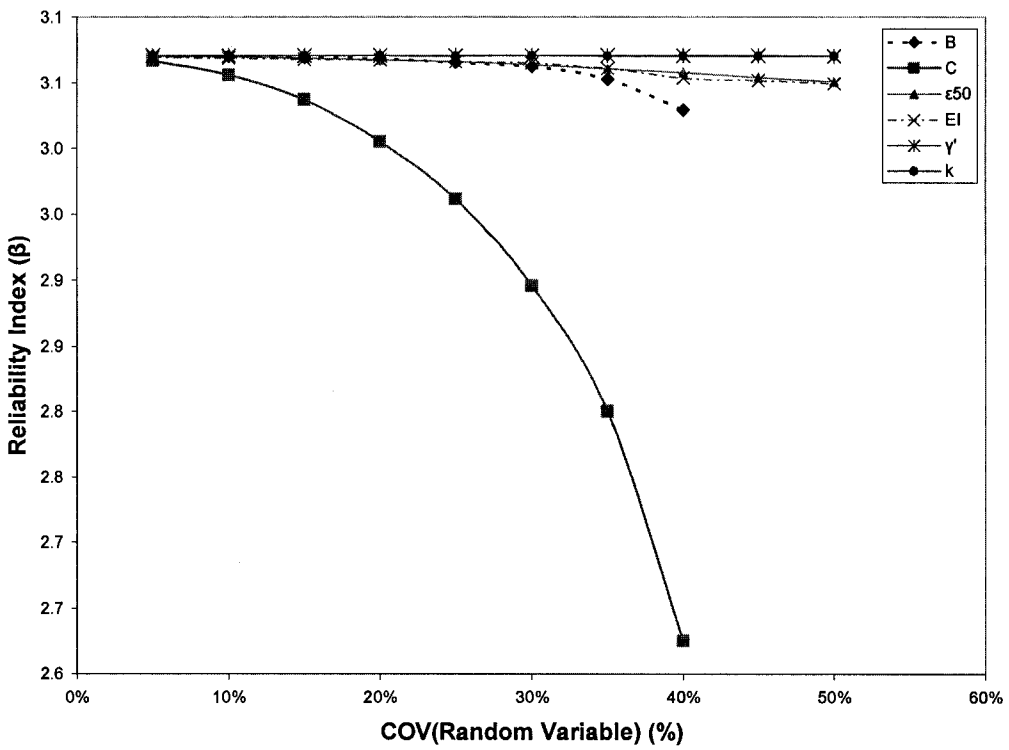

Fig. E.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single short pile (3T) at 305.25 kN lateral load.

For lateral load 340 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 492 \text{ kN.m}$$

Table E.43 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 340 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	9	31978.44	2.75	132.25	32101.69	2.75
10%	31969.44	30.25	31999.69	2.75	552.25	32521.69	2.73
15%	31969.44	64	32033.44	2.75	1332.25	33301.69	2.70
20%	31969.44	144	32113.44	2.75	2601	34570.44	2.65
25%	31969.44	324	32293.44	2.74	4761	36730.44	2.57
30%	31969.44	729	32698.44	2.72	8930.25	40899.69	2.43
35%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
40%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
45%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table E.44 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 340 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	4	31973.44	2.75	0.25	31969.69	2.75
10%	31969.44	16	31985.44	2.75	4	31973.44	2.75
15%	31969.44	42.25	32011.69	2.75	49	32018.44	2.75
20%	31969.44	72.25	32041.69	2.75	81	32050.44	2.75
25%	31969.44	132.25	32101.69	2.75	100	32069.44	2.75
30%	31969.44	182.25	32151.69	2.74	121	32090.44	2.75
35%	31969.44	240.25	32209.69	2.74	240.25	32209.69	2.74
40%	31969.44	342.25	32311.69	2.74	420.25	32389.69	2.73
45%	31969.44	380.25	32349.69	2.74	462.25	32431.69	2.73
50%	31969.44	441	32410.44	2.73	506.25	32475.69	2.73

Table E.45 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 340 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	2.75	0	31969.44	2.75
10%	31969.44	0	31969.44	2.75	0	31969.44	2.75
15%	31969.44	0	31969.44	2.75	0	31969.44	2.75
20%	31969.44	0	31969.44	2.75	0.25	31969.69	2.75
25%	31969.44	0.25	31969.69	2.75	0	31969.44	2.75
30%	31969.44	0.25	31969.69	2.75	0	31969.44	2.75
35%	31969.44	0.25	31969.69	2.75	0	31969.44	2.75
40%	31969.44	0.25	31969.69	2.75	0.25	31969.69	2.75
45%	31969.44	1	31970.44	2.75	0.25	31969.69	2.75
50%	31969.44	1	31970.44	2.75	0.25	31969.69	2.75

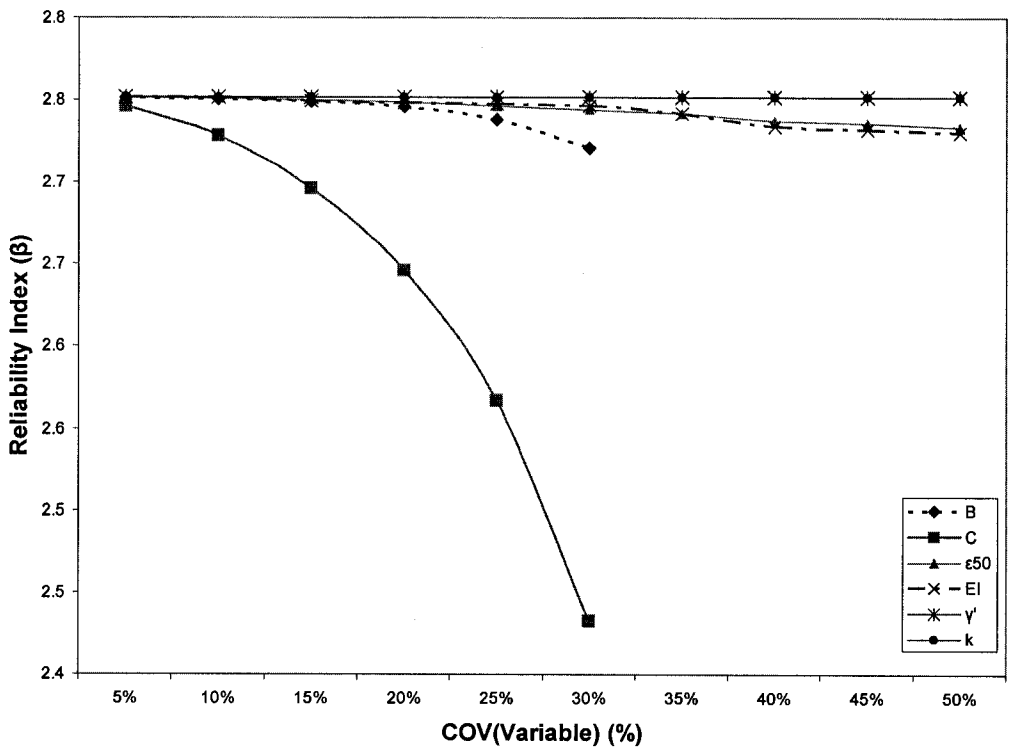

Fig. E.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single short pile (3T) at 340 kN lateral load.

For lateral load 375 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 427 \text{ kN.m}$$

Table E.46 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'B' and 'C' and applied lateral load 375 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	20.25	31989.69	2.39	256	32225.44	2.38
10%	31969.44	90.25	32059.69	2.38	1056.25	33025.69	2.35
15%	31969.44	256	32225.44	2.38	2601	34570.44	2.30
20%	31969.44	600.25	32569.69	2.37	5852.25	37821.69	2.20
25%	31969.44	1936	33905.44	2.32	175561	207530.44	0.94
30%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
35%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
40%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
45%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table E.47 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'ε_{50}' and 'EI' and applied lateral load 375 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1	31970.44	2.39	25	31994.44	2.39
10%	31969.44	20.25	31989.69	2.39	42.25	32011.69	2.39
15%	31969.44	49	32018.44	2.39	64	32033.44	2.39
20%	31969.44	81	32050.44	2.39	81	32050.44	2.39
25%	31969.44	121	32090.44	2.38	100	32069.44	2.38
30%	31969.44	169	32138.44	2.38	110.25	32079.69	2.38
35%	31969.44	225	32194.44	2.38	225	32194.44	2.38
40%	31969.44	289	32258.44	2.38	380.25	32349.69	2.37
45%	31969.44	324	32293.44	2.38	420.25	32389.69	2.37
50%	31969.44	380.25	32349.69	2.37	441	32410.44	2.37

Table E.48 Reliability Index connected to M_{Max} for fixed head single short pile (3T) with varying 'γ'' and 'k' and applied lateral load 375 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	2.39	0	31969.44	2.39
10%	31969.44	0	31969.44	2.39	0	31969.44	2.39
15%	31969.44	0	31969.44	2.39	0	31969.44	2.39
20%	31969.44	0	31969.44	2.39	0.25	31969.69	2.39
25%	31969.44	0.25	31969.69	2.39	0.25	31969.69	2.39
30%	31969.44	0.25	31969.69	2.39	0.25	31969.69	2.39
35%	31969.44	1	31970.44	2.39	0	31969.44	2.39
40%	31969.44	1	31970.44	2.39	0.25	31969.69	2.39
45%	31969.44	1	31970.44	2.39	0.25	31969.69	2.39
50%	31969.44	1	31970.44	2.39	0.25	31969.69	2.39

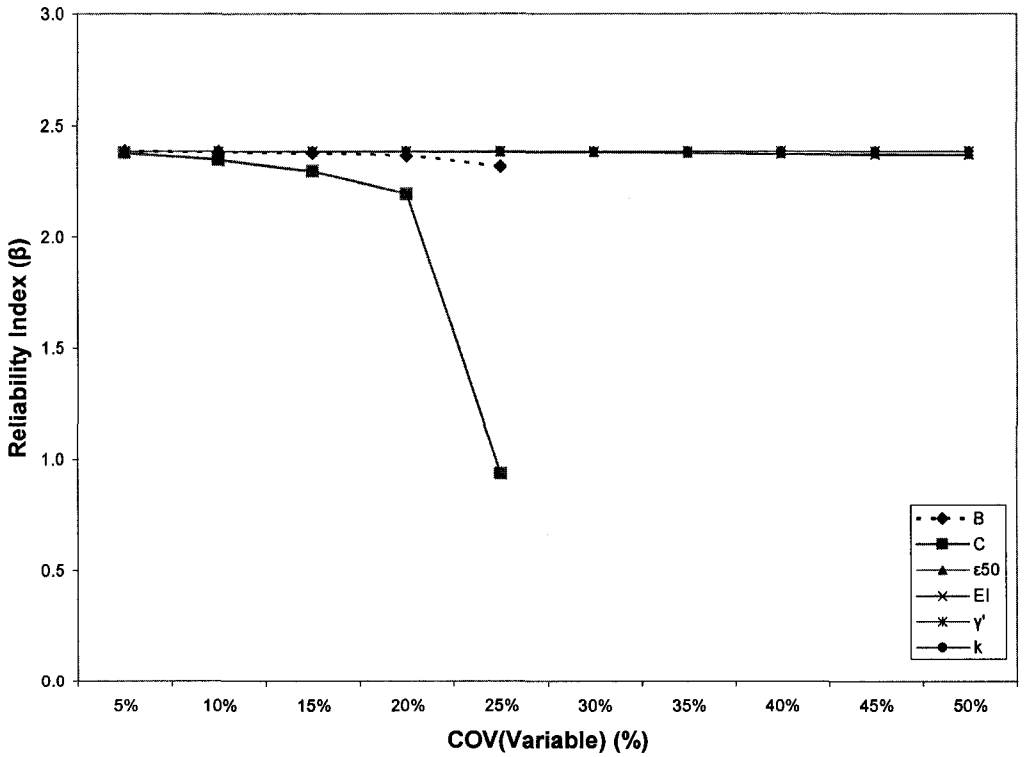

Fig. E.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single short pile (3T) at 375 kN lateral load.

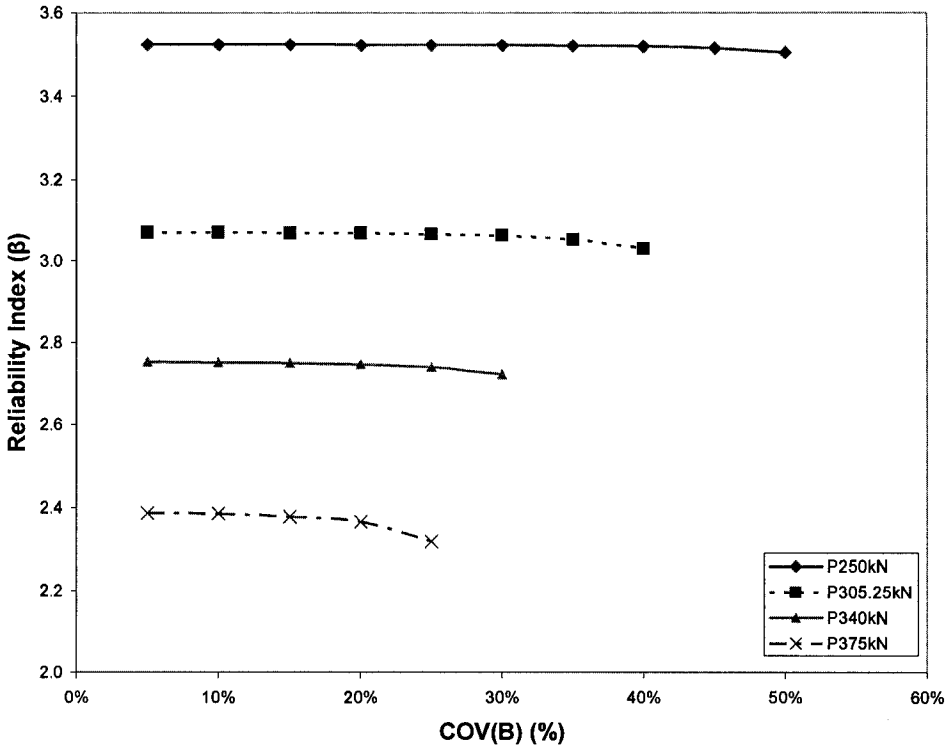

Fig. E.27 Reliability Index related to M_{Max} for fixed head short pile with varying 'B'.

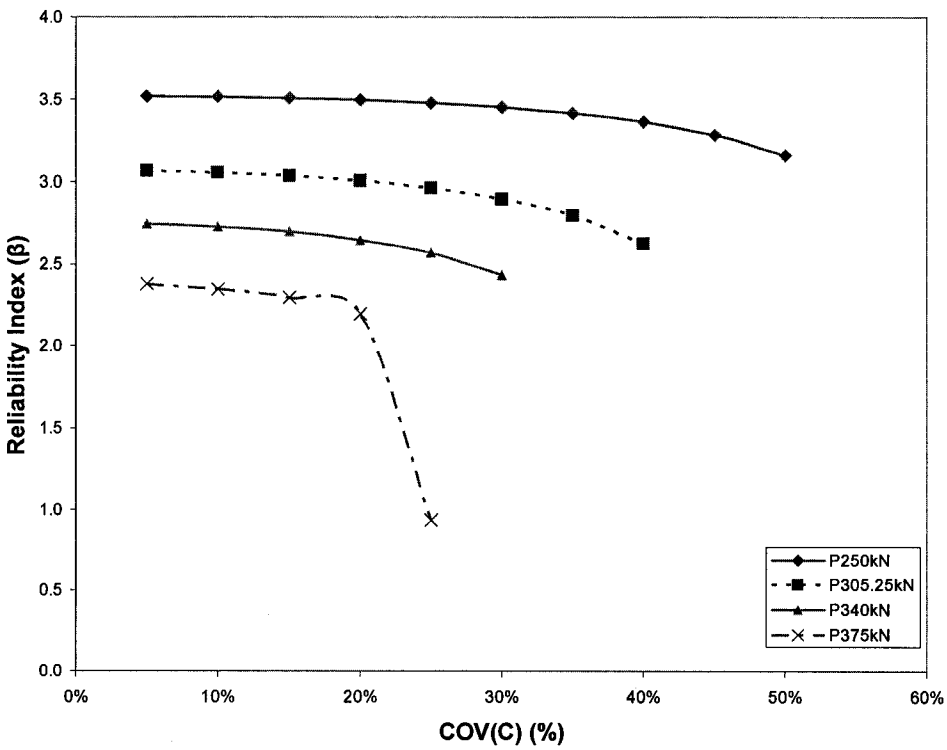

Fig. E.28 Reliability Index related to M_{Max} for fixed head short pile with varying 'C'.

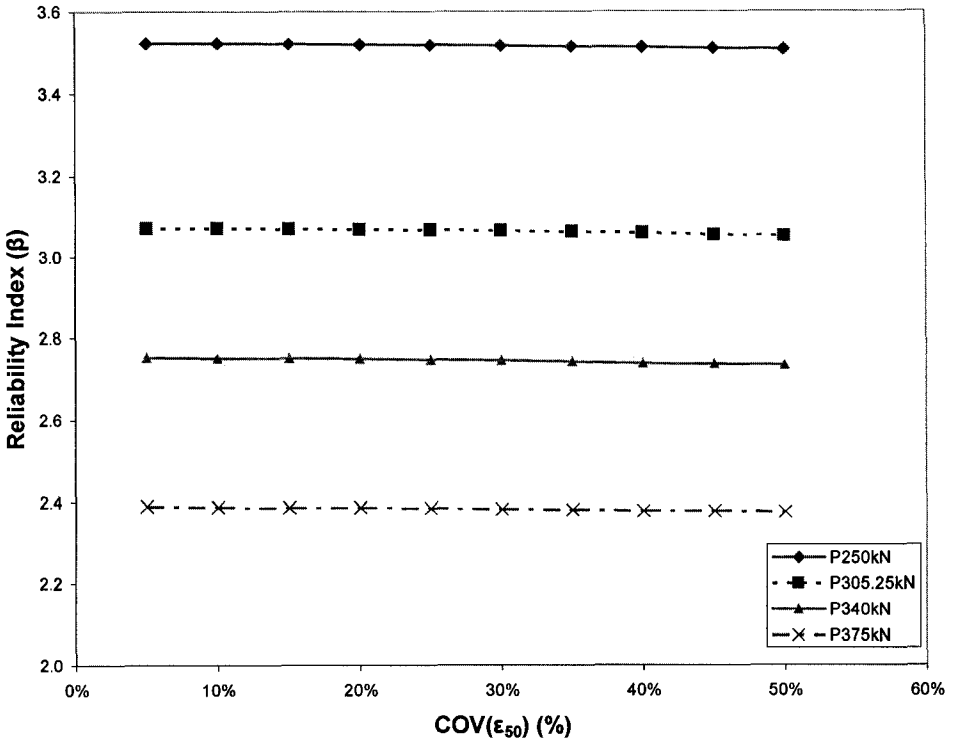

Fig.E.29 Reliability Index related to M_{Max} for fixed head short pile with varying 'ε_{50}'

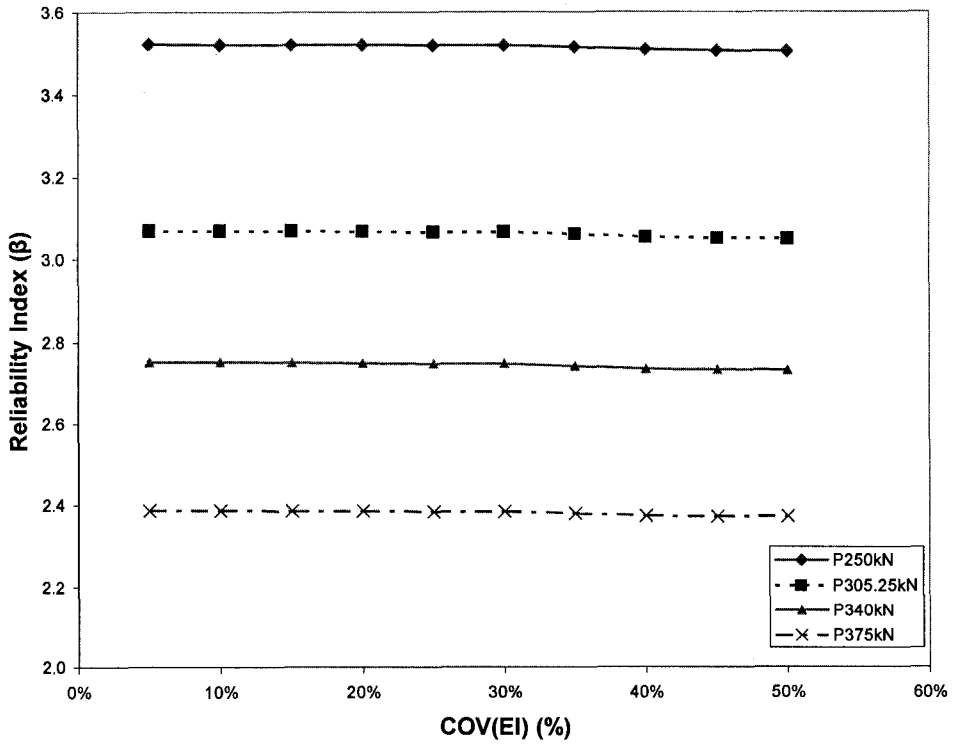

Fig.E.30 Reliability Index related to M_{Max} for fixed head short pile with varying 'EI'

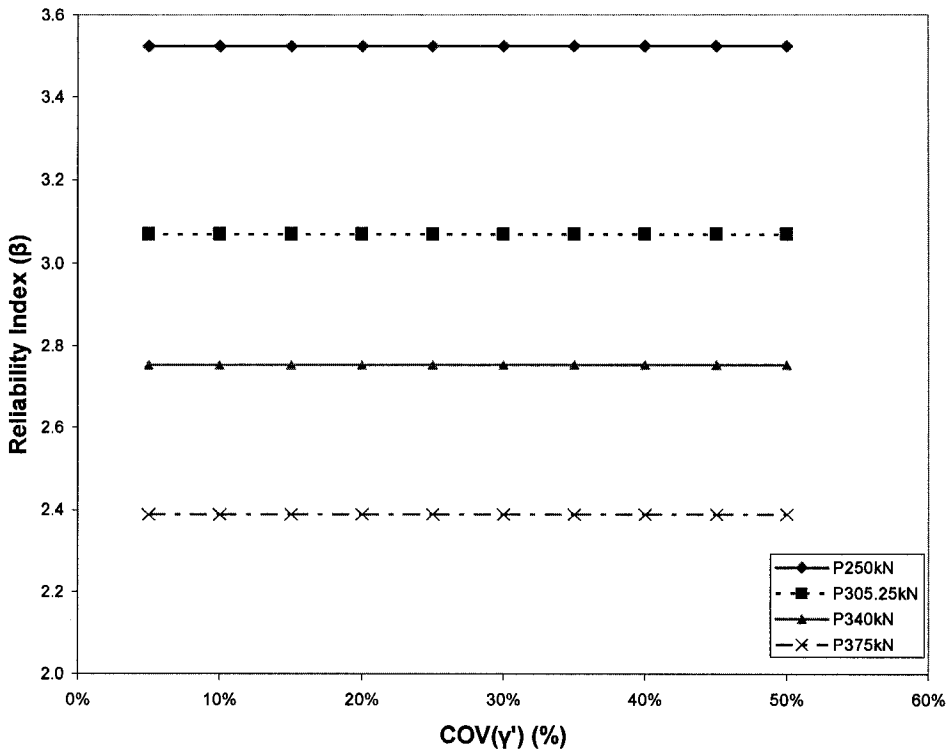

Fig. E.31 Reliability Index related to M_{Max} for fixed head short pile with varying 'γ'.

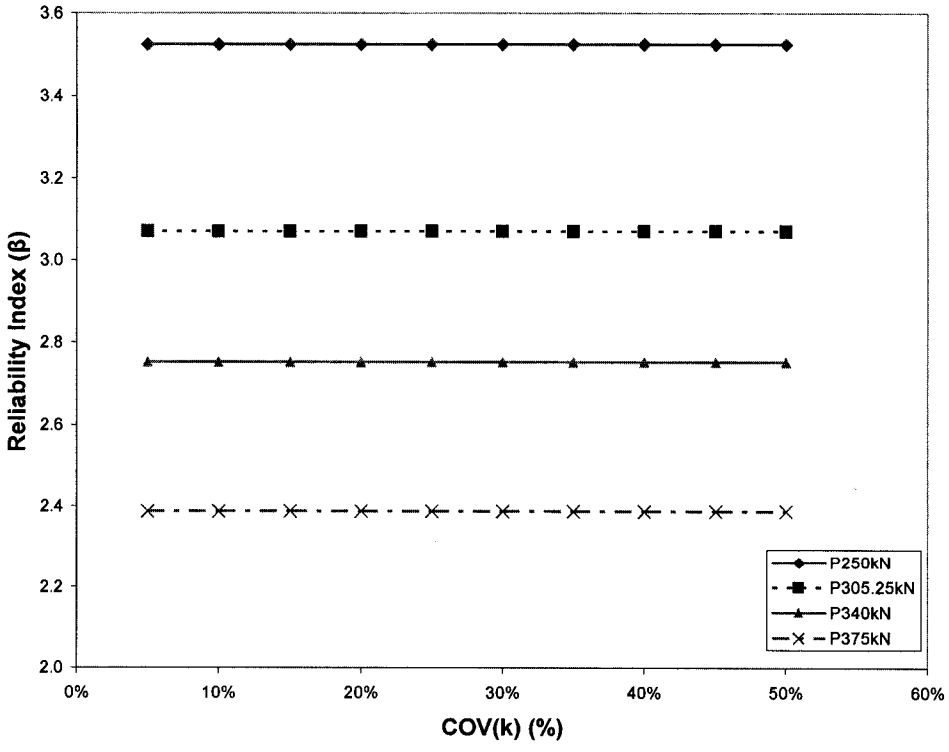

Fig. E.32 Reliability Index related to M_{Max} for fixed head short pile with varying 'k'.

APPENDIX F

LATERALLY LOADED FIXED HEAD SINGLE LONG PILE (10T)

F.1.1 Probabilistic modeling of laterally loaded fixed head single long pile (10T) with 'B' as varying random design variable

Table F.1. Values of Y_{Top} for fixed head single long pile (10T) with varying 'B' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	Ytop current (m)	Ytop current (m)	Ytop current (m)	Ytop current (m)
50%	0.064516	0.254	0.00474	0.00975		
45%	0.052258	0.2794	0.00443	0.00723		
40%	0.0412902	0.3048	0.00422	0.00644	0.0091	
35%	0.0316128	0.3302	0.00405	0.00591	0.00794	0.0115
30%	0.0232258	0.3556	0.00387	0.00565	0.00731	0.00968
25%	0.016129	0.381	0.00379	0.00549	0.00692	0.00885
20%	0.0103226	0.4064	0.00371	0.00535	0.00653	0.00832
15%	0.0058064	0.4318	0.00365	0.00523	0.00636	0.00798
10%	0.0025806	0.4572	0.00361	0.00515	0.00625	0.0077
5%	0.0006452	0.4826	0.00358	0.00509	0.00616	0.00753
0%	0	0.508	0.00354	0.005	0.00603	0.00737
5%	0.0006452	0.5334	0.00354	0.00501	0.00603	0.00718
10%	0.0025806	0.5588	0.00353	0.00497	0.00598	0.00711
15%	0.0058064	0.5842	0.00352	0.00495	0.00595	0.00706
20%	0.0103226	0.6096	0.00352	0.0049	0.00592	0.00702
25%	0.016129	0.635	0.00352	0.00489	0.0059	0.00698
30%	0.0232258	0.6604	0.00352	0.00488	0.00589	0.00696
35%	0.0316128	0.6858	0.00352	0.00488	0.00588	0.00695
40%	0.0412902	0.7112	0.00352	0.00488	0.00588	0.00693
45%	0.052258	0.7366	0.00353	0.00488	0.00588	0.00692
50%	0.064516	0.762	0.00353	0.00488	0.00587	0.00692

Table F.2. Values of M_{Max} for fixed head single long pile (10T) with varying 'B' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	Mmax current (kN-m)	Mmax current (kN-m)	Mmax current (kN-m)	Mmax current (kN-m)
50%	0.064516	0.254	-292	-435	Failed	Failed
45%	0.052258	0.2794	-286	-389	Failed	Failed
40%	0.0412902	0.3048	-282	-374	-456	Failed
35%	0.0316128	0.3302	-279	-364	-434	-532
30%	0.0232258	0.3556	-275	-359	-422	-499
25%	0.016129	0.381	-273	-356	-415	-484
20%	0.0103226	0.4064	-272	-354	-408	-474
15%	0.0058064	0.4318	-271	-351	-405	-468
10%	0.0025806	0.4572	-270	-350	-403	-463
5%	0.0006452	0.4826	-270	-349	-401	-460
0%	0	0.508	-269	-347	-399	-457
5%	0.0006452	0.5334	-269	-347	-399	-454
10%	0.0025806	0.5588	-269	-347	-398	-453
15%	0.0058064	0.5842	-269	-347	-398	-452
20%	0.0103226	0.6096	-269	-345	-397	-451
25%	0.016129	0.635	-269	-345	-397	-450
30%	0.0232258	0.6604	-269	-345	-396	-450
35%	0.0316128	0.6858	-269	-344	-396	-449
40%	0.0412902	0.7112	-269	-344	-396	-449
45%	0.052258	0.7366	-269	-344	-396	-448
50%	0.064516	0.762	-269	-344	-396	-448

Table F.3(a) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'B' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	6.45E-04	4.00E-10	0.565%	1.60E-09	0.800%
10.00%	2.58E-03	1.60E-09	1.130%	8.10E-09	1.800%
15.00%	5.81E-03	4.23E-09	1.836%	1.96E-08	2.800%
20.00%	1.03E-02	9.03E-09	2.684%	5.06E-08	4.500%
25.00%	1.61E-02	1.82E-08	3.814%	9.00E-08	6.000%
30.00%	2.32E-02	3.06E-08	4.944%	1.48E-07	7.700%
35.00%	3.16E-02	7.02E-08	7.486%	2.65E-07	10.300%
40.00%	4.13E-02	1.23E-07	9.887%	6.08E-07	15.600%
45.00%	5.23E-02	2.03E-07	12.712%	1.38E-06	23.500%
50.00%	6.45E-02	3.66E-07	17.090%	5.93E-06	48.700%

Table F.3(b) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'B' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	6.45E-04	4.22E-09	1.078%	3.06E-08	2.374%
10.00%	2.58E-03	1.82E-08	2.239%	8.70E-08	4.003%
15.00%	5.81E-03	4.20E-08	3.400%	2.12E-07	6.242%
20.00%	1.03E-02	9.30E-08	5.058%	4.23E-07	8.820%
25.00%	1.61E-02	2.60E-07	8.458%	8.74E-07	12.687%
30.00%	2.32E-02	5.04E-07	11.774%	1.85E-06	18.453%
35.00%	3.16E-02	1.06E-06	17.081%	5.18E-06	30.868%
40.00%	4.13E-02	2.59E-06	26.700%	Failed	Failed
45.00%	5.23E-02	Failed	Failed	Failed	Failed
50.00%	6.45E-02	Failed	Failed	Failed	Failed

Table F.4(a) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'B' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	0.0006452	0.25	0.186%	1	0.288%
10.00%	0.0025806	0.25	0.186%	2.25	0.432%
15.00%	0.0058064	1	0.372%	4	0.576%
20.00%	0.0103226	2.25	0.558%	20.25	1.297%
25.00%	0.016129	4	0.743%	30.25	1.585%
30.00%	0.0232258	9	1.115%	49	2.017%
35.00%	0.0316128	25	1.859%	100	2.882%
40.00%	0.0412902	42.25	2.416%	225	4.323%
45.00%	0.052258	72.25	3.160%	506.25	6.484%
50.00%	0.064516	132.25	4.275%	2070.25	13.112%

Table F.4(b) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'B' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	0.0006452	1	0.251%	9	0.656%
10.00%	0.0025806	6.25	0.627%	25	1.094%
15.00%	0.0058064	12.25	0.877%	64	1.751%
20.00%	0.0103226	30.25	1.378%	132.25	2.516%
25.00%	0.016129	81	2.256%	289	3.720%
30.00%	0.0232258	169	3.258%	600.25	5.361%
35.00%	0.0316128	361	4.762%	1722.25	9.081%
40.00%	0.0412902	900	7.519%	Failed	Failed
45.00%	0.052258	Failed	Failed	Failed	Failed
50.00%	0.064516	Failed	Failed	Failed	Failed

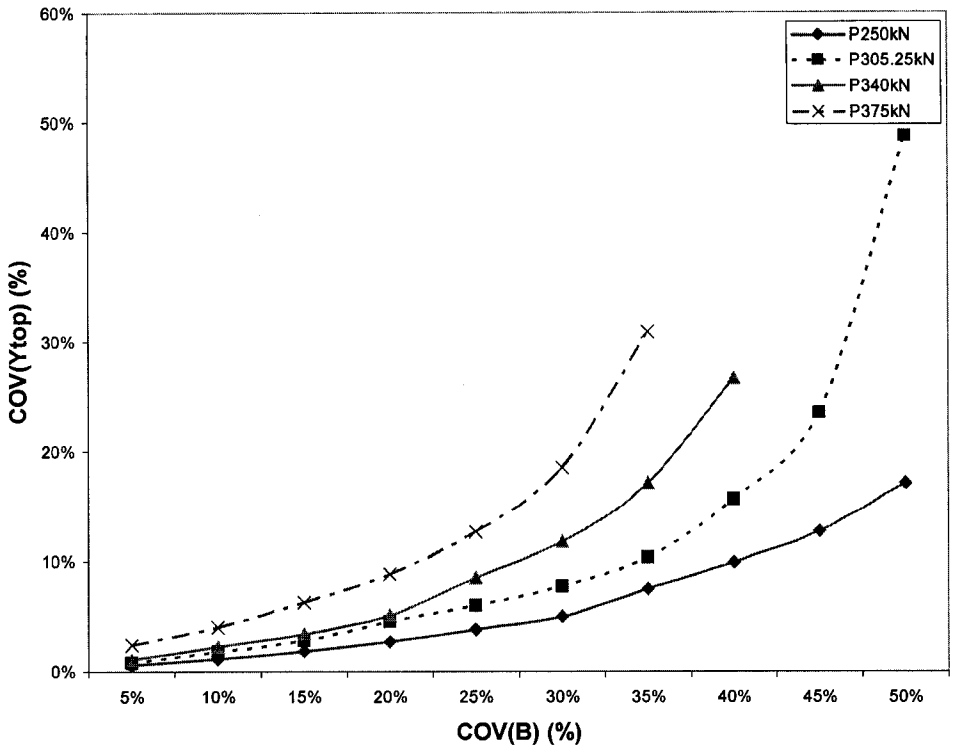

Fig. F.1 COV(Y_{Top}) for varying COV(B) in fixed head long pile (10T).

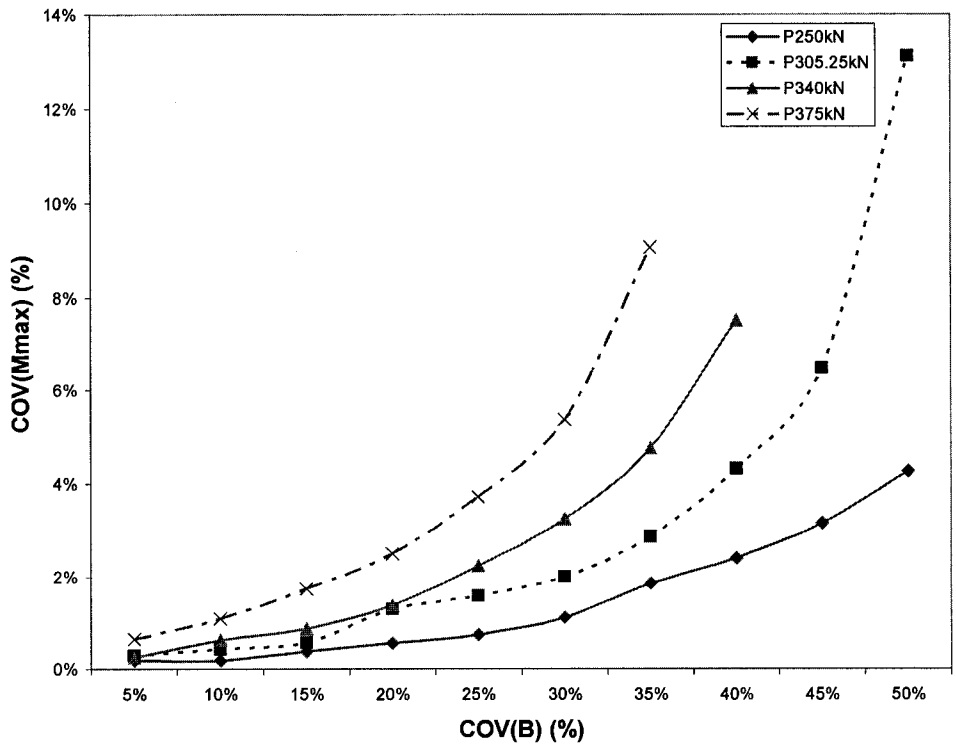

Fig. F.2 COV(M_{Max}) for varying COV(B) in fixed head long pile (10T).

F.1.2 Probabilistic modeling of laterally loaded fixed head single short pile (3T) with 'C' as varying random design variable

Table F.5. Values of Y_{Top} for fixed head single long pile (10T) with varying 'C' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50.00%	1406.25	37.5	0.00826	0.0139	0.141	Failed
45.00%	1139.0625	41.25	0.00719	0.0115	0.0162	Failed
40.00%	900	45	0.00636	0.0099	0.0133	0.0197
35.00%	689.0625	48.75	0.00571	0.00873	0.0114	0.0153
30.00%	506.25	52.5	0.00518	0.00782	0.01	0.0131
25.00%	351.5625	56.25	0.00482	0.00708	0.009	0.0115
20.00%	225	60	0.0045	0.00653	0.00816	0.0103
15.00%	126.5625	63.75	0.00423	0.00595	0.00747	0.00932
10.00%	56.25	67.5	0.00398	0.00559	0.00695	0.00853
5.00%	14.0625	71.25	0.00377	0.00528	0.00638	0.00787
0.00%	0	75	0.00354	0.005	0.00603	0.00737
5.00%	14.0625	78.75	0.00336	0.00475	0.00572	0.00682
10.00%	56.25	82.5	0.0032	0.00452	0.00544	0.00648
15.00%	126.5625	86.25	0.00306	0.00427	0.00519	0.00617
20.00%	225	90	0.00293	0.00408	0.00496	0.00589
25.00%	351.5625	93.75	0.00281	0.0039	0.0047	0.00563
30.00%	506.25	97.5	0.0027	0.00374	0.0045	0.00536
35.00%	689.0625	101.25	0.0026	0.0036	0.00432	0.00514
40.00%	900	105	0.00251	0.00346	0.00415	0.00493
45.00%	1139.0625	108.75	0.00242	0.00334	0.004	0.00474
50.00%	1406.25	112.5	0.00235	0.00323	0.00386	0.00457

Table F.6. Values of M_{Max} for fixed head single long pile (10T) with varying 'C' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50.00%	1406.25	37.5	-360	-496	-1250	Failed
45.00%	1139.0625	41.25	-343	-464	-565	Failed
40.00%	900	45	-329	-440	-525	-650
35.00%	689.0625	48.75	-317	-421	-497	-592
30.00%	506.25	52.5	-307	-405	-476	-559
25.00%	351.5625	56.25	-299	-391	-458	-533
20.00%	225	60	-292	-380	-443	-513
15.00%	126.5625	63.75	-286	-369	-429	-496
10.00%	56.25	67.5	-280	-361	-419	-481
5.00%	14.0625	71.25	-275	-354	-407	-468
0.00%	0	75	-269	-347	-399	-457
5.00%	14.0625	78.75	-264	-341	-392	-445
10.00%	56.25	82.5	-260	-335	-385	-437
15.00%	126.5625	86.25	-256	-328	-378	-430
20.00%	225	90	-252	-323	-373	-423
25.00%	351.5625	93.75	-248	-318	-365	-416
30.00%	506.25	97.5	-245	-314	-360	-409
35.00%	689.0625	101.25	-242	-310	-355	-403
40.00%	900	105	-239	-305	-350	-397
45.00%	1139.0625	108.75	-236	-302	-345	-392
50.00%	1406.25	112.5	-233	-298	-341	-387

Table F.7(a) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'C' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	4.20E-08	5.791%	7.02E-08	5.300%
10.00%	5.63E+01	1.52E-07	11.017%	2.86E-07	10.700%
15.00%	1.27E+02	3.42E-07	16.525%	7.06E-07	16.800%
20.00%	2.25E+02	6.16E-07	22.175%	1.50E-06	24.500%
25.00%	3.52E+02	1.01E-06	28.390%	2.53E-06	31.800%
30.00%	5.06E+02	1.54E-06	35.028%	4.16E-06	40.800%
35.00%	6.89E+02	2.42E-06	43.927%	6.58E-06	51.300%
40.00%	9.00E+02	3.71E-06	54.379%	1.04E-05	64.400%
45.00%	1.14E+03	5.69E-06	67.373%	1.66E-05	81.600%
50.00%	1.41E+03	8.73E-06	83.475%	2.85E-05	106.700%

Table F.7(b) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'C' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	1.09E-07	5.473%	2.76E-07	7.123%
10.00%	5.63E+01	5.70E-07	12.521%	1.05E-06	13.908%
15.00%	1.27E+02	1.30E-06	18.905%	2.48E-06	21.370%
20.00%	2.25E+02	2.56E-06	26.534%	4.86E-06	29.919%
25.00%	3.52E+02	4.62E-06	35.655%	8.61E-06	39.824%
30.00%	5.06E+02	7.56E-06	45.605%	1.50E-05	52.510%
35.00%	6.89E+02	1.25E-05	58.706%	2.58E-05	68.928%
40.00%	9.00E+02	2.09E-05	75.871%	5.45E-05	100.204%
45.00%	1.14E+03	3.72E-05	101.161%	Failed	Failed
50.00%	1.41E+03	Failed	Failed	Failed	Failed

Table F.8(a) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'C' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	14.0625	30.25	2.045%	42.25	1.873%
10.00%	56.25	100	3.717%	169	3.746%
15.00%	126.5625	225	5.576%	420.25	5.908%
20.00%	225	400	7.435%	812.25	8.213%
25.00%	351.5625	650.25	9.480%	1332.25	10.519%
30.00%	506.25	961	11.524%	2070.25	13.112%
35.00%	689.0625	1406.25	13.941%	3080.25	15.994%
40.00%	900	2025	16.729%	4556.25	19.452%
45.00%	1139.0625	2862.25	19.888%	6561	23.343%
50.00%	1406.25	4032.25	23.606%	9801	28.530%

Table F.8(b) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'C' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5.00%	14.0625	56.25	1.880%	132.25	2.516%
10.00%	56.25	289	4.261%	484	4.814%
15.00%	126.5625	650.25	6.391%	1089	7.221%
20.00%	225	1225	8.772%	2025	9.847%
25.00%	351.5625	2162.25	11.654%	3422.25	12.801%
30.00%	506.25	3364	14.536%	5625	16.411%
35.00%	689.0625	5041	17.794%	8930.25	20.678%
40.00%	900	7656.25	21.930%	16002.25	27.681%
45.00%	1139.0625	12100	27.569%	Failed	Failed
50.00%	1406.25	Failed	Failed	Failed	Failed

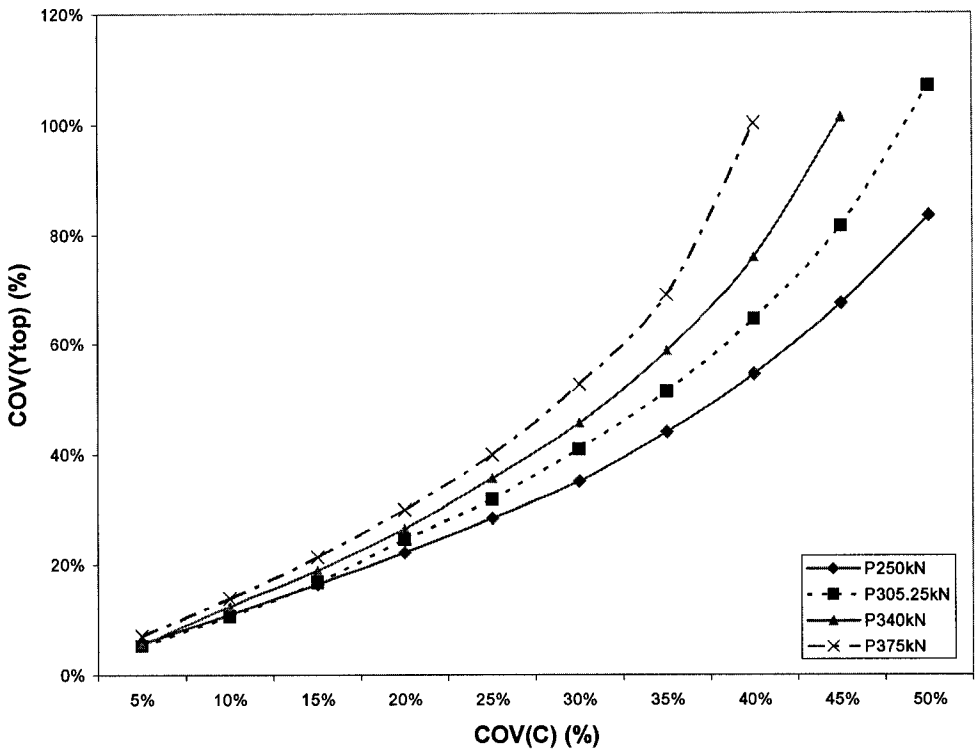

Fig. F.3 COV(Y_{Top}) for varying COV(C) in fixed head long pile (10T).

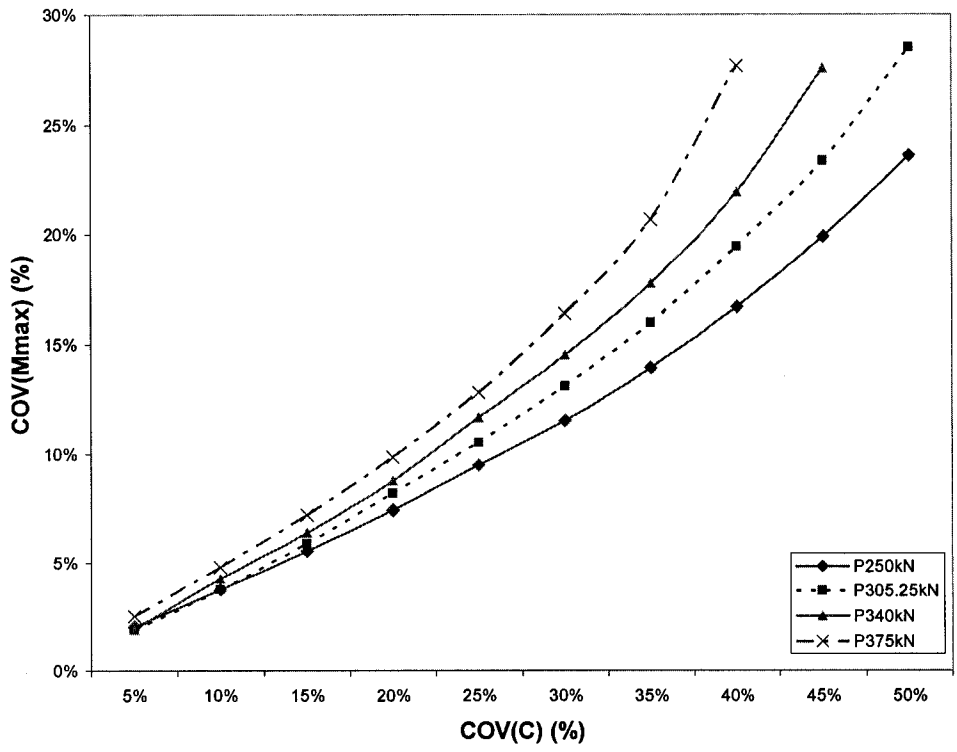

Fig. F.4 COV(M_{Max}) for varying COV(C) in fixed head long pile (10T).

F.1.3 Probabilistic modeling of laterally loaded fixed head single long pile (10T) with 'ε_{50}' as varying random design variable

Table F.9. Values of Y_{Top} for fixed head single long pile (10T) with varying 'ε_{50}' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	1.23E-05	0.0035	0.00277	0.00407	0.00502	0.00634
45%	9.92E-06	0.00385	0.00285	0.00417	0.00512	0.00642
40%	7.84E-06	0.0042	0.00293	0.00427	0.00522	0.00651
35%	6.00E-06	0.00455	0.00301	0.00436	0.00532	0.00661
30%	4.41E-06	0.0049	0.00309	0.00446	0.00543	0.00671
25%	3.06E-06	0.00525	0.00317	0.00455	0.00553	0.00682
20%	1.96E-06	0.0056	0.00325	0.00464	0.00564	0.00693
15%	1.10E-06	0.00595	0.00332	0.00473	0.00574	0.00704
10%	4.90E-07	0.0063	0.0034	0.00482	0.00584	0.00715
5%	1.23E-07	0.00665	0.00347	0.00491	0.00594	0.00726
0%	0.00E+00	0.007	0.00354	0.005	0.00603	0.00737
5%	1.23E-07	0.00735	0.00365	0.00508	0.00613	0.00748
10%	4.90E-07	0.0077	0.00372	0.00517	0.00622	0.00759
15%	1.10E-06	0.00805	0.00378	0.00525	0.00632	0.00769
20%	1.96E-06	0.0084	0.00385	0.00534	0.00641	0.0078
25%	3.06E-06	0.00875	0.00391	0.00542	0.0065	0.0079
30%	4.41E-06	0.0091	0.00397	0.0055	0.00659	0.00801
35%	6.00E-06	0.00945	0.00404	0.00558	0.00668	0.00811
40%	7.84E-06	0.0098	0.0041	0.00566	0.00677	0.00821
45%	9.92E-06	0.01015	0.00416	0.00573	0.00686	0.00832
50%	1.23E-05	0.0105	0.00422	0.00581	0.00695	0.00842

Table F.10. Values of M_{Max} for fixed head single long pile (10T) with varying 'ε_{50}' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	1.23E-05	0.0035	-251	-330	-383	-445
45%	9.92E-06	0.00385	-253	-332	-384	-445
40%	7.84E-06	0.0042	-255	-334	-386	-446
35%	6.00E-06	0.00455	-257	-335	-387	-447
30%	4.41E-06	0.0049	-259	-337	-389	-448
25%	3.06E-06	0.00525	-260	-339	-391	-449
20%	1.96E-06	0.0056	-262	-340	-392	-451
15%	1.10E-06	0.00595	-264	-342	-394	-452
10%	4.90E-07	0.0063	-266	-344	-396	-454
5%	1.23E-07	0.00665	-267	-345	-397	-455
0%	0.00E+00	0.007	-269	-347	-399	-457
5%	1.23E-07	0.00735	-272	-349	-401	-459
10%	4.90E-07	0.0077	-273	-350	-402	-460
15%	1.10E-06	0.00805	-274	-352	-404	-462
20%	1.96E-06	0.0084	-276	-353	-405	-463
25%	3.06E-06	0.00875	-277	-355	-407	-465
30%	4.41E-06	0.0091	-278	-356	-408	-466
35%	6.00E-06	0.00945	-280	-358	-410	-468
40%	7.84E-06	0.0098	-281	-359	-411	-469
45%	9.92E-06	0.01015	-282	-361	-413	-471
50%	1.23E-05	0.0105	-207	-362	-414	-472

Table F.11(a) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'ε_{50}' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	8.10E-09	2.542%	7.22E-09	1.700%
10%	4.90E-07	2.56E-08	4.520%	3.06E-08	3.500%
15%	1.10E-06	5.29E-08	6.497%	6.76E-08	5.200%
20%	1.96E-06	9.00E-08	8.475%	1.23E-07	7.000%
25%	3.06E-06	1.37E-07	10.452%	1.89E-07	8.700%
30%	4.41E-06	1.94E-07	12.429%	2.70E-07	10.400%
35%	6.00E-06	2.65E-07	14.548%	3.72E-07	12.200%
40%	7.84E-06	3.42E-07	16.525%	4.83E-07	13.900%
45%	9.92E-06	4.29E-07	18.503%	6.08E-07	15.600%
50%	1.23E-05	5.26E-07	20.480%	7.57E-07	17.400%

Table F.11(b) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'ε_{50}' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	9.02E-09	1.575%	1.21E-08	1.493%
10%	4.90E-07	3.61E-08	3.151%	4.84E-08	2.985%
15%	1.10E-06	8.41E-08	4.809%	1.06E-07	4.410%
20%	1.96E-06	1.48E-07	6.385%	1.89E-07	5.902%
25%	3.06E-06	2.35E-07	8.043%	2.92E-07	7.327%
30%	4.41E-06	3.36E-07	9.619%	4.23E-07	8.820%
35%	6.00E-06	4.62E-07	11.277%	5.62E-07	10.176%
40%	7.84E-06	6.01E-07	12.852%	7.23E-07	11.533%
45%	9.92E-06	7.57E-07	14.428%	9.03E-07	12.890%
50%	1.23E-05	9.31E-07	16.003%	1.08E-06	14.111%

Table F.12(a) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'ε_{50}' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	1.23E-07	6.25	0.929%	4	0.576%
10%	4.90E-07	12.25	1.301%	9	0.865%
15%	1.10E-06	25	1.859%	25	1.441%
20%	1.96E-06	49	2.602%	42.25	1.873%
25%	3.06E-06	72.25	3.160%	64	2.305%
30%	4.41E-06	90.25	3.532%	90.25	2.738%
35%	6.00E-06	132.25	4.275%	132.25	3.314%
40%	7.84E-06	169	4.833%	156.25	3.602%
45%	9.92E-06	210.25	5.390%	210.25	4.179%
50%	1.23E-05	484	8.178%	256	4.611%

Table F.12(b) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'ε_{50}' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	1.23E-07	4	0.501%	4	0.438%
10%	4.90E-07	9	0.752%	9	0.656%
15%	1.10E-06	25	1.253%	25	1.094%
20%	1.96E-06	42.25	1.629%	36	1.313%
25%	3.06E-06	64	2.005%	64	1.751%
30%	4.41E-06	90.25	2.381%	81	1.969%
35%	6.00E-06	132.25	2.882%	110.25	2.298%
40%	7.84E-06	156.25	3.133%	132.25	2.516%
45%	9.92E-06	210.25	3.634%	169	2.845%
50%	1.23E-05	240.25	3.885%	182.25	2.954%

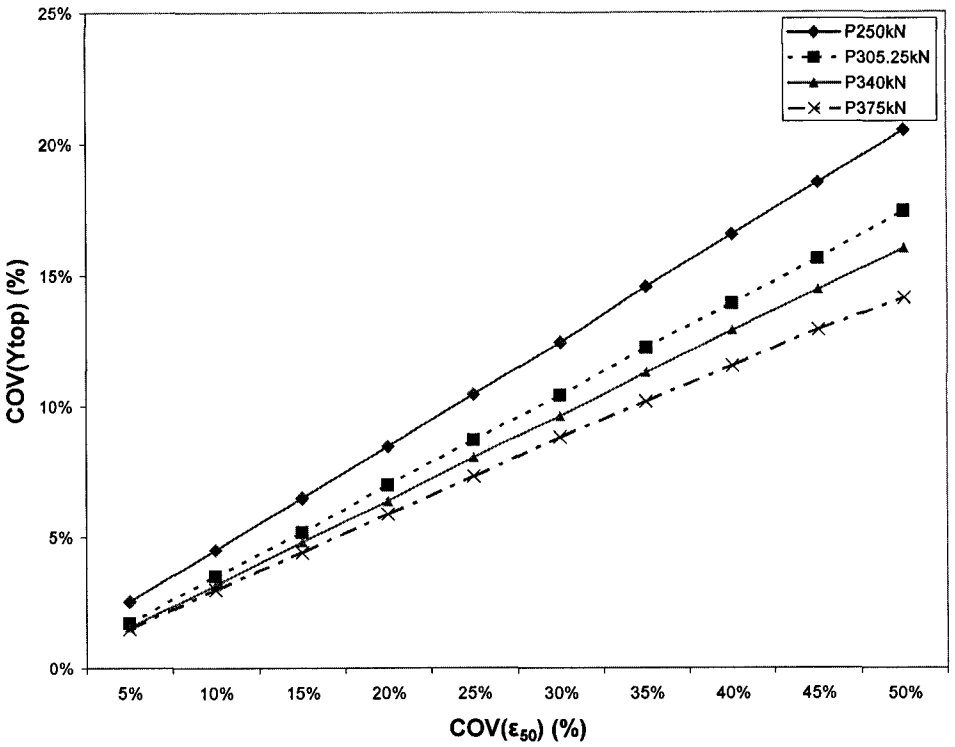

Fig. F.5 COV(Y_{Top}) for varying COV(ε_{50}) in fixed head long pile (10T).

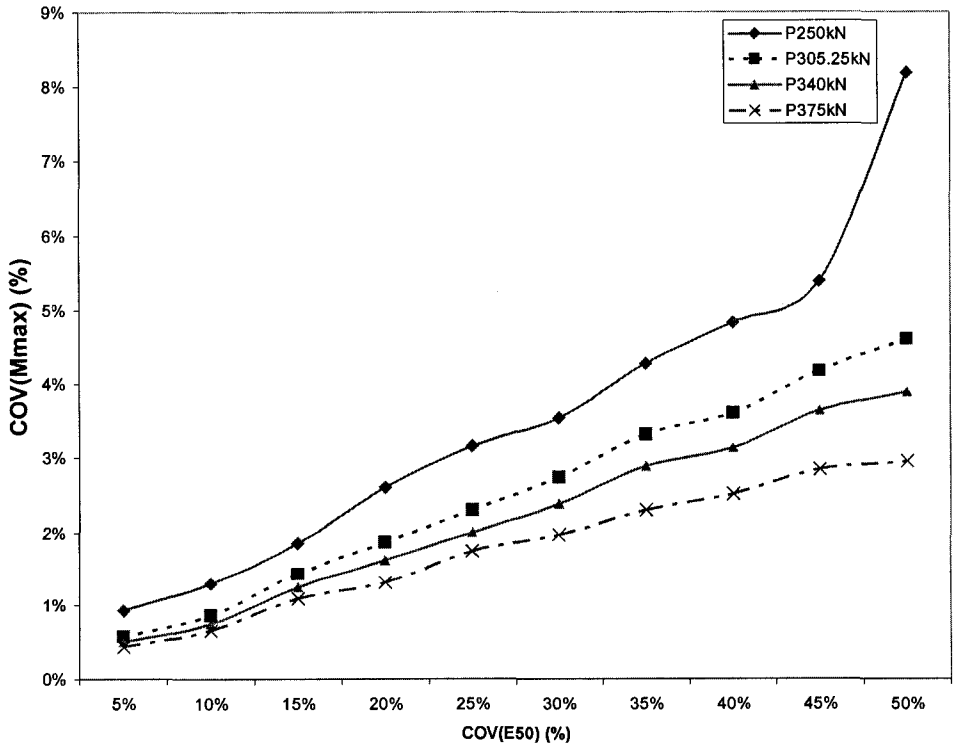

Fig. F.6 COV(M_{Max}) for varying COV(ε_{50}) in fixed head long pile (10T).

F.1.4 Probabilistic modeling of laterally loaded fixed head single long pile (10T) with 'EI' as varying random design variable

Table F.13 Values of Y_{Top} for fixed head single long pile (10T) with varying 'EI' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	3.03E+09	55000	0.00501	0.00719	0.00911	0.0115
45%	2.45E+09	60500	0.00486	0.00697	0.00873	0.0111
40%	1.94E+09	66000	0.00473	0.00677	0.00846	0.0106
35%	1.48E+09	71500	0.00461	0.00659	0.00822	0.0103
30%	1.09E+09	77000	0.00395	0.00563	0.00682	0.00837
25%	7.56E+08	82500	0.00387	0.00551	0.00667	0.00816
20%	4.84E+08	88000	0.0038	0.0054	0.00653	0.00798
15%	2.72E+08	93500	0.00373	0.0053	0.00635	0.00779
10%	1.21E+08	99000	0.00367	0.0052	0.00624	0.00764
5%	3.03E+07	104500	0.00361	0.00512	0.00613	0.0075
0%	0.00E+00	110000	0.00354	0.005	0.00603	0.00737
5%	3.03E+07	115500	0.00316	0.00445	0.00535	0.00636
10%	1.21E+08	121000	0.00312	0.00438	0.00527	0.00626
15%	2.72E+08	126500	0.00308	0.00433	0.0052	0.00618
20%	4.84E+08	132000	0.00304	0.00427	0.00513	0.00609
25%	7.56E+08	137500	0.00301	0.00422	0.00503	0.00597
30%	1.09E+09	143000	0.00299	0.00417	0.00498	0.0059
35%	1.48E+09	148500	0.00296	0.0041	0.00492	0.00584
40%	1.94E+09	154000	0.00271	0.00374	0.00447	0.00529
45%	2.45E+09	159500	0.00269	0.0037	0.00443	0.00523
50%	3.03E+09	165000	0.00266	0.00366	0.00438	0.00518

Table F.14. Values of M_{Max} for fixed head single long pile (10T) with varying 'EI' and lateral load P.

		P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	3.03E+09	-252	-329	-385	-447
45%	2.45E+09	-254	-330	-384	-447
40%	1.94E+09	-255	-332	-386	-447
35%	1.48E+09	-256	-333	-386	-447
30%	1.09E+09	-264	-342	-394	-451
25%	7.56E+08	-265	-343	-395	-453
20%	4.84E+08	-266	-344	-396	-454
15%	2.72E+08	-267	-345	-396	-454
10%	1.21E+08	-268	-346	-397	-455
5%	3.03E+07	-268	-347	-398	-456
0%	0.00E+00	-269	-347	-399	-457
5%	3.03E+07	-276	-356	-408	-464
10%	1.21E+08	-277	-357	-409	-465
15%	2.72E+08	-278	-358	-410	-466
20%	4.84E+08	-279	-359	-411	-467
25%	7.56E+08	-280	-360	-411	-467
30%	1.09E+09	-281	-360	-412	-468
35%	1.48E+09	-282	-360	-413	-468
40%	1.94E+09	-289	-369	-422	-478
45%	2.45E+09	-289	-370	-423	-479
50%	3.03E+09	-290	-370	-424	-480

Table F.15(a) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'EI' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	5.06E-08	6.356%	1.12E-07	6.700%
10%	1.21E+08	7.56E-08	7.768%	1.68E-07	8.200%
15%	2.72E+08	1.06E-07	9.181%	2.35E-07	9.700%
20%	4.84E+08	1.44E-07	10.734%	3.19E-07	11.300%
25%	7.56E+08	1.85E-07	12.147%	4.16E-07	12.900%
30%	1.09E+09	2.30E-07	13.559%	5.33E-07	14.600%
35%	1.48E+09	6.81E-07	23.305%	1.55E-06	24.900%
40%	1.94E+09	1.02E-06	28.531%	2.30E-06	30.300%
45%	2.45E+09	1.18E-06	30.650%	2.67E-06	32.700%
50%	3.03E+09	1.38E-06	33.192%	3.12E-06	35.300%

Table F.15(b) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'EI' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	1.52E-07	6.468%	3.25E-07	7.734%
10%	1.21E+08	2.35E-07	8.043%	4.76E-07	9.362%
15%	2.72E+08	3.31E-07	9.536%	6.48E-07	10.923%
20%	4.84E+08	4.90E-07	11.609%	8.93E-07	12.822%
25%	7.56E+08	6.72E-07	13.599%	1.20E-06	14.858%
30%	1.09E+09	8.46E-07	15.257%	1.53E-06	16.757%
35%	1.48E+09	2.72E-06	27.363%	4.97E-06	30.258%
40%	1.94E+09	3.98E-06	33.085%	7.05E-06	36.024%
45%	2.45E+09	4.62E-06	35.655%	8.61E-06	39.824%
50%	3.03E+09	5.59E-06	39.221%	9.99E-06	42.877%

Table F.16(a) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'EI' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	16	1.487%	20.25	1.297%
10%	1.21E+08	20.25	1.673%	30.25	1.585%
15%	2.72E+08	30.25	2.045%	42.25	1.873%
20%	4.84E+08	42.25	2.416%	56.25	2.161%
25%	7.56E+08	56.25	2.788%	72.25	2.450%
30%	1.09E+09	72.25	3.160%	81	2.594%
35%	1.48E+09	169	4.833%	182.25	3.890%
40%	1.94E+09	289	6.320%	342.25	5.331%
45%	2.45E+09	306.25	6.506%	400	5.764%
50%	3.03E+09	361	7.063%	420.25	5.908%

Table F.16(b) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'EI' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	3.03E+07	25	1.253%	16	0.875%
10%	1.21E+08	36	1.504%	25	1.094%
15%	2.72E+08	49	1.754%	36	1.313%
20%	4.84E+08	56.25	1.880%	42.25	1.422%
25%	7.56E+08	64	2.005%	49	1.532%
30%	1.09E+09	81	2.256%	72.25	1.860%
35%	1.48E+09	182.25	3.383%	110.25	2.298%
40%	1.94E+09	324	4.511%	240.25	3.392%
45%	2.45E+09	380.25	4.887%	256	3.501%
50%	3.03E+09	380.25	4.887%	272.25	3.611%

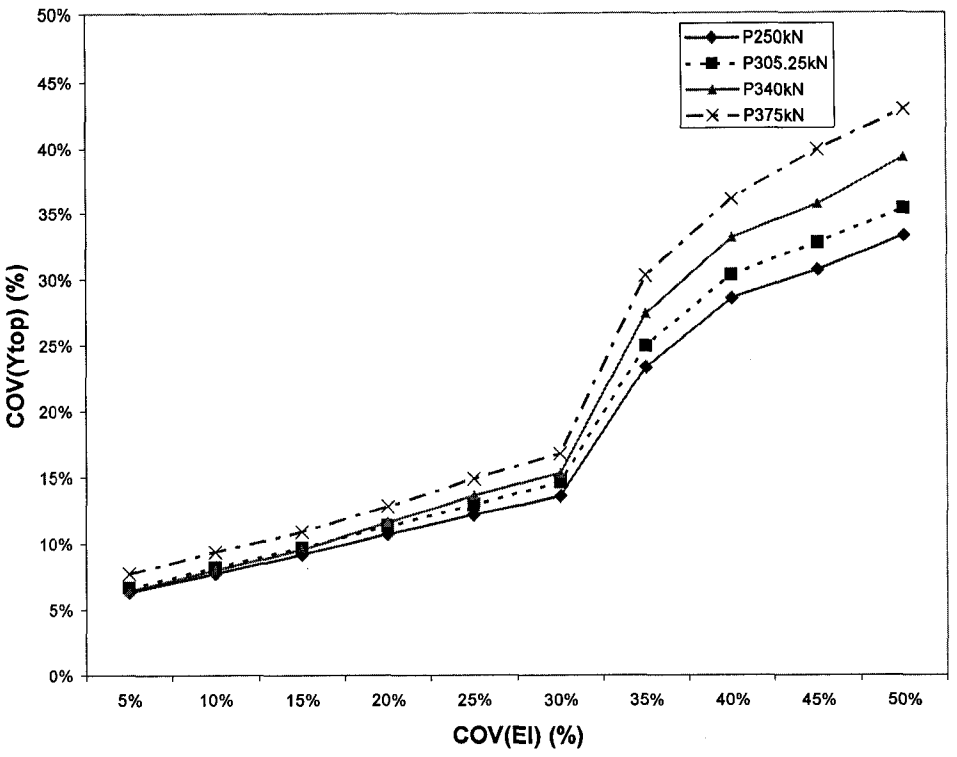

Fig. F.7 COV(Y_{Top}) for varying COV(EI) in fixed head long pile (10T).

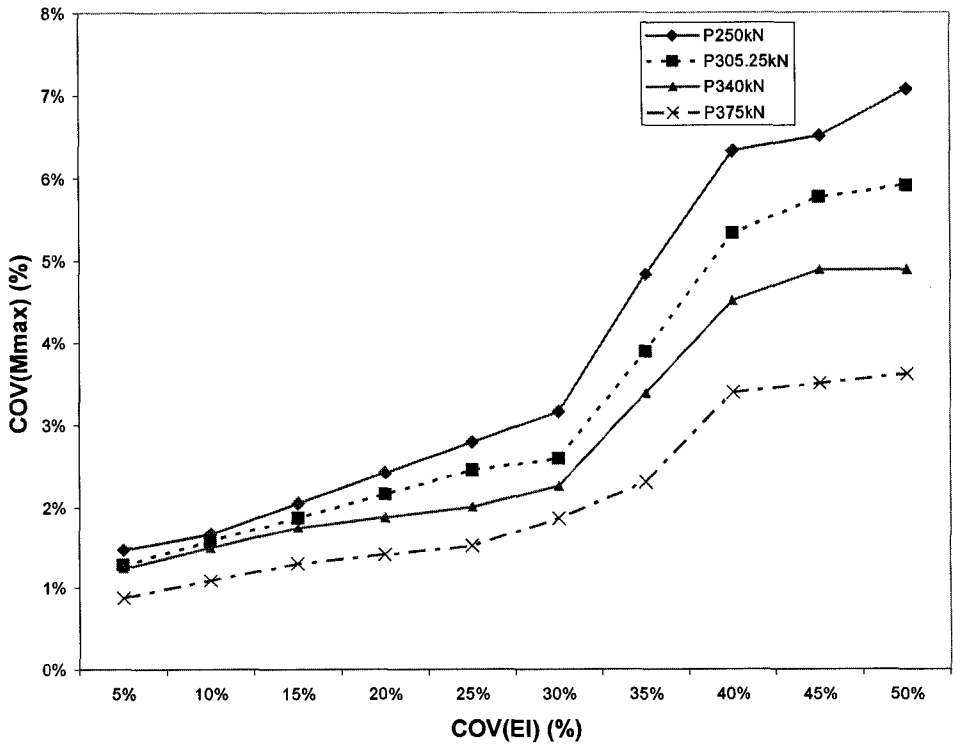

Fig. F.8 COV(M_{Max}) for varying COV(EI) in fixed head long pile (10T).

F.1.5 Probabilistic modeling of laterally loaded fixed head single long pile (10T) with 'k' as varying random design variable

Table F.17 Values of Y_{Top} for fixed head single long pile (10T) with varying 'k' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	4.62E+09	68000	0.00359	0.00508	0.0062	0.00749
45%	3.75E+09	74800	0.00358	0.00507	0.0062	0.00744
40%	2.96E+09	81600	0.00358	0.00505	0.00619	0.00741
35%	2.27E+09	88400	0.00357	0.00504	0.00616	0.00737
30%	1.66E+09	95200	0.00356	0.00503	0.00614	0.00734
25%	1.16E+09	102000	0.00356	0.00506	0.00612	0.00731
20%	7.40E+08	108800	0.00356	0.00505	0.0061	0.00729
15%	4.16E+08	115600	0.00355	0.00503	0.00608	0.00734
10%	1.85E+08	122400	0.00355	0.00502	0.00606	0.00733
5%	4.62E+07	129200	0.00354	0.00501	0.00605	0.00732
0%	0.00E+00	136000	0.00354	0.005	0.00603	0.00737
5%	4.62E+07	142800	0.00357	0.00499	0.00602	0.00736
10%	1.85E+08	149600	0.00357	0.00498	0.006	0.00736
15%	4.16E+08	156400	0.00356	0.00497	0.00599	0.00735
20%	7.40E+08	163200	0.00356	0.00496	0.00598	0.00734
25%	1.16E+09	170000	0.00355	0.00495	0.00597	0.00734
30%	1.66E+09	176800	0.00355	0.00494	0.00595	0.00733
35%	2.27E+09	183600	0.00354	0.00493	0.00594	0.00732
40%	2.96E+09	190400	0.00354	0.00493	0.00593	0.00738
45%	3.75E+09	197200	0.00353	0.00492	0.006	0.00738
50%	4.62E+09	204000	0.00353	0.00491	0.006	0.00737

Table F.18. Values of M_{Max} for fixed head single long pile (10T) with varying 'k' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	4.62E+09	68000	-270	-349	-402	-460
45%	3.75E+09	74800	-270	-348	-402	-459
40%	2.96E+09	81600	-270	-348	-402	-458
35%	2.27E+09	88400	-269	-348	-402	-457
30%	1.66E+09	95200	-269	-348	-401	-457
25%	1.16E+09	102000	-269	-348	-401	-456
20%	7.40E+08	108800	-269	-348	-400	-456
15%	4.16E+08	115600	-269	-348	-400	-456
10%	1.85E+08	122400	-269	-348	-400	-456
5%	4.62E+07	129200	-269	-347	-399	-456
0%	0.00E+00	136000	-269	-347	-399	-457
5%	4.62E+07	142800	-270	-347	-399	-457
10%	1.85E+08	149600	-270	-347	-398	-457
15%	4.16E+08	156400	-270	-346	-398	-457
20%	7.40E+08	163200	-270	-346	-398	-456
25%	1.16E+09	170000	-269	-346	-398	-456
30%	1.66E+09	176800	-269	-346	-397	-456
35%	2.27E+09	183600	-269	-346	-397	-456
40%	2.96E+09	190400	-269	-346	-397	-457
45%	3.75E+09	197200	-269	-345	-398	-457
50%	4.62E+09	204000	-269	-345	-398	-457

Table F.19(a) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'k' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.25E-10	0.424%	1.00E-10	0.200%
10%	1.85E+08	1.00E-10	0.282%	4.00E-10	0.400%
15%	4.16E+08	2.50E-11	0.141%	9.00E-10	0.600%
20%	7.40E+08	0.00E+00	0.000%	2.02E-09	0.900%
25%	1.16E+09	2.50E-11	0.141%	3.02E-09	1.100%
30%	1.66E+09	2.50E-11	0.141%	2.02E-09	0.900%
35%	2.27E+09	2.25E-10	0.424%	3.02E-09	1.100%
40%	2.96E+09	4.00E-10	0.565%	3.60E-09	1.200%
45%	3.75E+09	6.25E-10	0.706%	5.63E-09	1.500%
50%	4.62E+09	9.00E-10	0.847%	7.23E-09	1.700%

Table F.19(b) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'k' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.25E-10	0.249%	4.00E-10	0.271%
10%	1.85E+08	9.00E-10	0.498%	2.25E-10	0.204%
15%	4.16E+08	2.03E-09	0.746%	2.50E-11	0.068%
20%	7.40E+08	3.60E-09	0.995%	6.25E-10	0.339%
25%	1.16E+09	5.63E-09	1.244%	2.25E-10	0.204%
30%	1.66E+09	9.02E-09	1.575%	2.50E-11	0.068%
35%	2.27E+09	1.21E-08	1.824%	6.25E-10	0.339%
40%	2.96E+09	1.69E-08	2.156%	2.25E-10	0.204%
45%	3.75E+09	1.00E-08	1.658%	9.00E-10	0.407%
50%	4.62E+09	1.00E-08	1.658%	3.60E-09	0.814%

Table F.20(a) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'k' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0.25	0.186%	0	0.000%
10%	1.85E+08	0.25	0.186%	0.25	0.144%
15%	4.16E+08	0.25	0.186%	1	0.288%
20%	7.40E+08	0.25	0.186%	1	0.288%
25%	1.16E+09	0	0.000%	1	0.288%
30%	1.66E+09	0	0.000%	1	0.288%
35%	2.27E+09	0	0.000%	1	0.288%
40%	2.96E+09	0.25	0.186%	1	0.288%
45%	3.75E+09	0.25	0.186%	2.25	0.432%
50%	4.62E+09	0.25	0.186%	4	0.576%

Table F.20(b) Value of COV(M_{Max}) for fixed head single long pile (3T) with varying 'k' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN-m)^2$	COV(M_{Max}) (%)
5%	4.62E+07	0	0.000%	0.25	0.109%
10%	1.85E+08	1	0.251%	0.25	0.109%
15%	4.16E+08	1	0.251%	0.25	0.109%
20%	7.40E+08	1	0.251%	0	0.000%
25%	1.16E+09	2.25	0.376%	0	0.000%
30%	1.66E+09	4	0.501%	0.25	0.109%
35%	2.27E+09	6.25	0.627%	0.25	0.109%
40%	2.96E+09	6.25	0.627%	0.25	0.109%
45%	3.75E+09	4	0.501%	1	0.219%
50%	4.62E+09	4	0.501%	2.25	0.328%

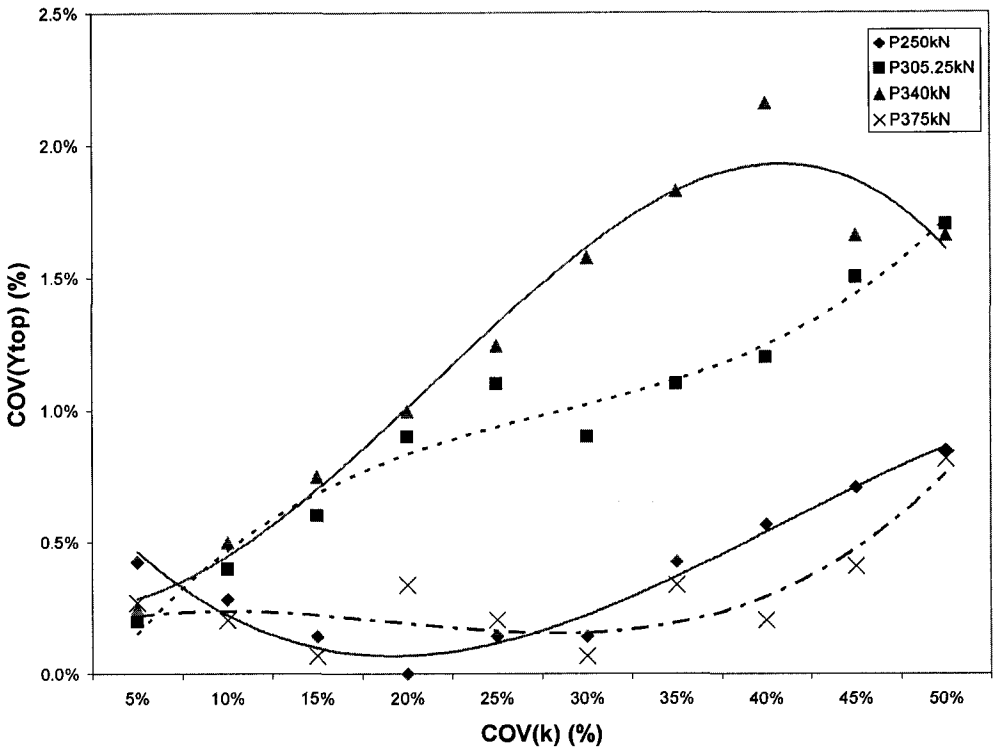

Fig. F.9 COV(Y_{Top}) for varying COV(k) in fixed head long pile (3T).

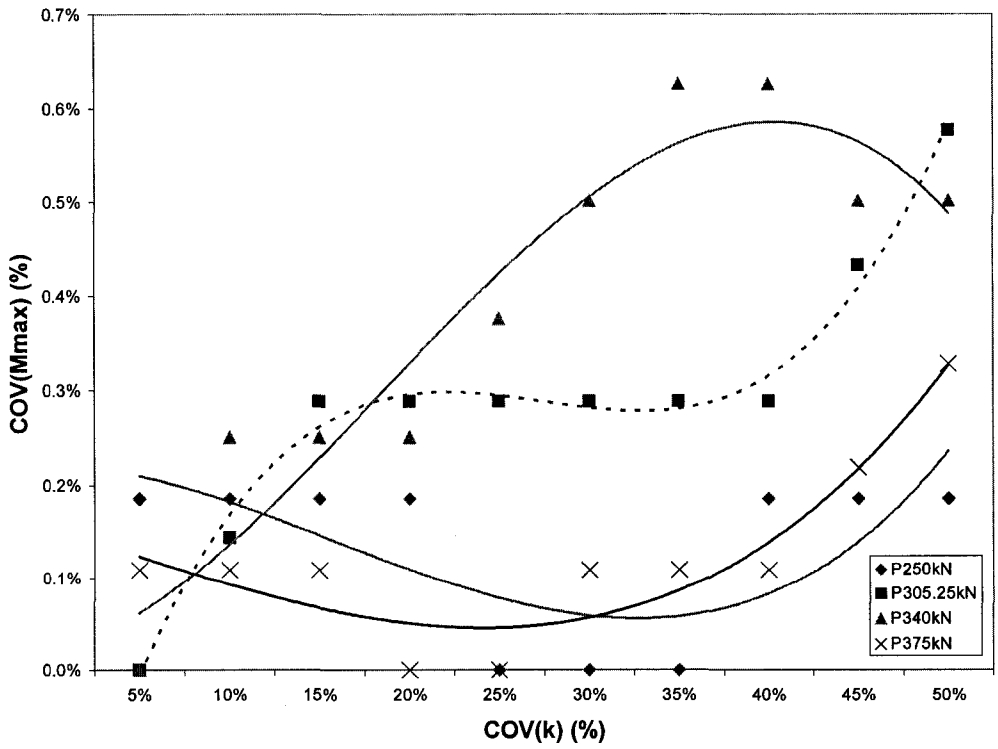

Fig. F.10 COV(M_{Max}) for varying COV(k) in fixed head long pile (10T).

F.1.6 Probabilistic modeling of laterally loaded fixed head single long pile (10T) with 'γ' as varying random design variable

Table F.21 Values of Y_{Top} for fixed head single long pile (10T) with varying 'γ' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)	Y_{Top} current (m)
50%	8.70E+00	2.95	0.00359	0.00501	0.00605	0.0074
45%	7.05E+00	3.245	0.00359	0.00501	0.00605	0.0074
40%	5.57E+00	3.54	0.00355	0.00501	0.00605	0.0074
35%	4.26E+00	3.835	0.00355	0.00501	0.00605	0.00739
30%	3.13E+00	4.13	0.00355	0.00501	0.00604	0.00739
25%	2.18E+00	4.425	0.00355	0.00501	0.00604	0.00738
20%	1.39E+00	4.72	0.00355	0.005	0.00604	0.00738
15%	7.83E-01	5.015	0.00354	0.005	0.00604	0.00738
10%	3.48E-01	5.31	0.00354	0.005	0.00604	0.00738
5%	8.70E-02	5.605	0.00354	0.005	0.00603	0.00737
0%	0.00E+00	5.9	0.00354	0.005	0.00603	0.00737
5%	8.70E-02	6.195	0.00354	0.005	0.00603	0.00737
10%	3.48E-01	6.49	0.00354	0.00499	0.00603	0.00737
15%	7.83E-01	6.785	0.00354	0.00499	0.00603	0.00736
20%	1.39E+00	7.08	0.00354	0.00499	0.00602	0.00736
25%	2.18E+00	7.375	0.00353	0.00499	0.00602	0.00736
30%	3.13E+00	7.67	0.00353	0.00499	0.00602	0.00735
35%	4.26E+00	7.965	0.00353	0.00499	0.00602	0.00735
40%	5.57E+00	8.26	0.00353	0.00498	0.00602	0.00735
45%	7.05E+00	8.555	0.00353	0.00498	0.00601	0.00734
50%	8.70E+00	8.85	0.00353	0.00498	0.00601	0.00734

Table F.22. Values of M_{Max} for fixed head single long pile (10T) with varying 'γ'' and lateral load P.

			P=250 kN	P=305.25 kN	P=340 kN	P=375 kN
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)	M_{Max} current (kN-m)
50%	8.70E+00	2.95	-270	-348	-400	-458
45%	7.05E+00	3.245	-270	-348	-400	-458
40%	5.57E+00	3.54	-269	-348	-399	-458
35%	4.26E+00	3.835	-269	-348	-399	-457
30%	3.13E+00	4.13	-269	-348	-399	-457
25%	2.18E+00	4.425	-269	-347	-399	-457
20%	1.39E+00	4.72	-269	-347	-399	-457
15%	7.83E-01	5.015	-269	-347	-399	-457
10%	3.48E-01	5.31	-269	-347	-399	-457
5%	8.70E-02	5.605	-269	-347	-399	-457
0%	0.00E+00	5.9	-269	-347	-399	-457
5%	8.70E-02	6.195	-269	-347	-399	-457
10%	3.48E-01	6.49	-269	-347	-399	-457
15%	7.83E-01	6.785	-269	-347	-399	-457
20%	1.39E+00	7.08	-269	-347	-399	-457
25%	2.18E+00	7.375	-269	-347	-399	-457
30%	3.13E+00	7.67	-269	-347	-399	-457
35%	4.26E+00	7.965	-269	-347	-399	-457
40%	5.57E+00	8.26	-268	-347	-399	-457
45%	7.05E+00	8.555	-268	-347	-398	-456
50%	8.70E+00	8.85	-268	-347	-398	-456

Table F.23(a) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'γ' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	0.00E+00	0.000%
10%	3.48E-01	0.00E+00	0.000%	2.50E-11	0.100%
15%	7.83E-01	0.00E+00	0.000%	2.50E-11	0.100%
20%	1.39E+00	2.50E-11	0.141%	2.50E-11	0.100%
25%	2.18E+00	1.00E-10	0.282%	1.00E-10	0.200%
30%	3.13E+00	1.00E-10	0.282%	1.00E-10	0.200%
35%	4.26E+00	1.00E-10	0.282%	1.00E-10	0.200%
40%	5.57E+00	1.00E-10	0.282%	2.25E-10	0.300%
45%	7.05E+00	9.00E-10	0.847%	2.25E-10	0.300%
50%	8.70E+00	9.00E-10	0.847%	2.25E-10	0.300%

Table 23(b) Value of COV(Y_{Top}) for fixed head single long pile (10T) with varying 'γ' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	0.00E+00	0.000%
10%	3.48E-01	2.50E-11	0.083%	2.50E-11	0.068%
15%	7.83E-01	2.50E-11	0.083%	1.00E-10	0.136%
20%	1.39E+00	1.00E-10	0.166%	1.00E-10	0.136%
25%	2.18E+00	1.00E-10	0.166%	1.00E-10	0.136%
30%	3.13E+00	1.00E-10	0.166%	4.00E-10	0.271%
35%	4.26E+00	2.25E-10	0.249%	4.00E-10	0.271%
40%	5.57E+00	2.25E-10	0.249%	6.25E-10	0.339%
45%	7.05E+00	4.00E-10	0.332%	9.00E-10	0.407%
50%	8.70E+00	4.00E-10	0.332%	9.00E-10	0.407%

Table F.24(a) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'γ' and lateral load 250 kN and 305.25 kN.

		P=250 kN		P=305.25 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	8.70E-02	0	0.000%	0	0.000%
10%	3.48E-01	0	0.000%	0	0.000%
15%	7.83E-01	0	0.000%	0	0.000%
20%	1.39E+00	0	0.000%	0	0.000%
25%	2.18E+00	0	0.000%	0	0.000%
30%	3.13E+00	0	0.000%	0.25	0.144%
35%	4.26E+00	0	0.000%	0.25	0.144%
40%	5.57E+00	0.25	0.186%	0.25	0.144%
45%	7.05E+00	1	0.372%	0.25	0.144%
50%	8.70E+00	1	0.372%	0.25	0.144%

Table F.24(b) Value of COV(M_{Max}) for fixed head single long pile (10T) with varying 'γ' and lateral load 340 kN and 375 kN.

		P=340 kN		P=375 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)	VAR(M_{Max}) $(kN\text{-}m)^2$	COV(M_{Max}) (%)
5%	8.70E-02	0	0.000%	0	0.000%
10%	3.48E-01	0	0.000%	0	0.000%
15%	7.83E-01	0	0.000%	0	0.000%
20%	1.39E+00	0	0.000%	0	0.000%
25%	2.18E+00	0	0.000%	0	0.000%
30%	3.13E+00	0	0.000%	0	0.000%
35%	4.26E+00	0	0.000%	0	0.000%
40%	5.57E+00	0	0.000%	0.25	0.109%
45%	7.05E+00	1	0.251%	1	0.219%
50%	8.70E+00	1	0.251%	1	0.219%

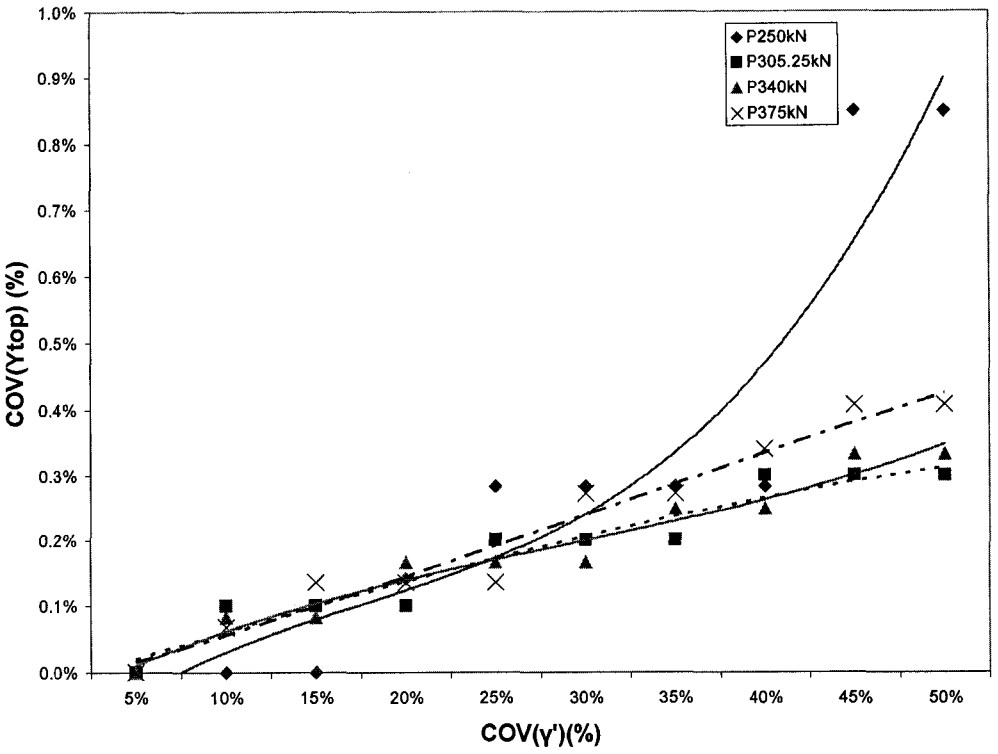

Fig. F.11 COV(Y_{Top}) for varying COV(γ') in fixed head long pile (10T).

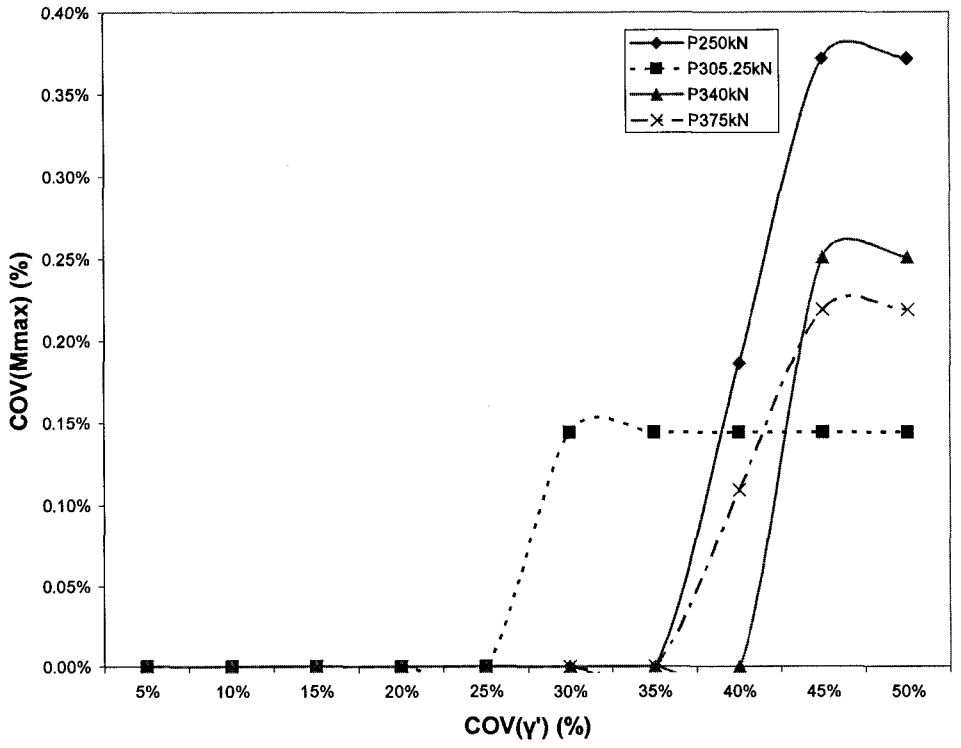

Fig. F.12 COV(M_{Max}) for varying COV(γ') in fixed head long pile (10T).

E.2 Reliability analysis of fixed head single long pile

E.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 250 kN

$g(Y_{top})^o = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00946$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06$ m^2

Table F.25 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 250 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	4.00E-10	6.76E-06	3.64	4.20E-08	6.80E-06	3.63
10%	6.76E-06	1.60E-09	6.76E-06	3.64	1.52E-07	6.91E-06	3.60
15%	6.76E-06	4.23E-09	6.76E-06	3.64	3.42E-07	7.10E-06	3.55
20%	6.76E-06	9.03E-09	6.77E-06	3.64	6.16E-07	7.38E-06	3.48
25%	6.76E-06	1.82E-08	6.78E-06	3.63	1.01E-06	7.77E-06	3.39
30%	6.76E-06	3.06E-08	6.79E-06	3.63	1.54E-06	8.30E-06	3.28
35%	6.76E-06	7.02E-08	6.83E-06	3.62	2.42E-06	9.18E-06	3.12
40%	6.76E-06	1.23E-07	6.88E-06	3.61	3.71E-06	1.05E-05	2.92
45%	6.76E-06	2.03E-07	6.96E-06	3.59	5.69E-06	1.24E-05	2.68
50%	6.76E-06	3.66E-07	7.13E-06	3.54	8.73E-06	1.55E-05	2.40

Table F.26 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 250 kN.

		ε50			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	8.10E-09	6.77E-06	3.64	5.06E-08	6.81E-06	3.62
10%	6.76E-06	2.56E-08	6.79E-06	3.63	7.56E-08	6.84E-06	3.62
15%	6.76E-06	5.29E-08	6.81E-06	3.62	1.06E-07	6.87E-06	3.61
20%	6.76E-06	9.00E-08	6.85E-06	3.61	1.44E-07	6.90E-06	3.60
25%	6.76E-06	1.37E-07	6.90E-06	3.60	1.85E-07	6.94E-06	3.59
30%	6.76E-06	1.94E-07	6.95E-06	3.59	2.30E-07	6.99E-06	3.58
35%	6.76E-06	2.65E-07	7.03E-06	3.57	6.81E-07	7.44E-06	3.47
40%	6.76E-06	3.42E-07	7.10E-06	3.55	1.02E-06	7.78E-06	3.39
45%	6.76E-06	4.29E-07	7.19E-06	3.53	1.18E-06	7.94E-06	3.36
50%	6.76E-06	5.26E-07	7.29E-06	3.50	1.38E-06	8.14E-06	3.32

Table F.27 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 250 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.64	2.25E-10	6.76E-06	3.64
10%	6.76E-06	0.00E+00	6.76E-06	3.64	1.00E-10	6.76E-06	3.64
15%	6.76E-06	0.00E+00	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
20%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
25%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
30%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
35%	6.76E-06	1.00E-10	6.76E-06	3.64	2.25E-10	6.76E-06	3.64
40%	6.76E-06	1.00E-10	6.76E-06	3.64	4.00E-10	6.76E-06	3.64
45%	6.76E-06	9.00E-10	6.76E-06	3.64	6.25E-10	6.76E-06	3.64
50%	6.76E-06	9.00E-10	6.76E-06	3.64	9.00E-10	6.76E-06	3.64

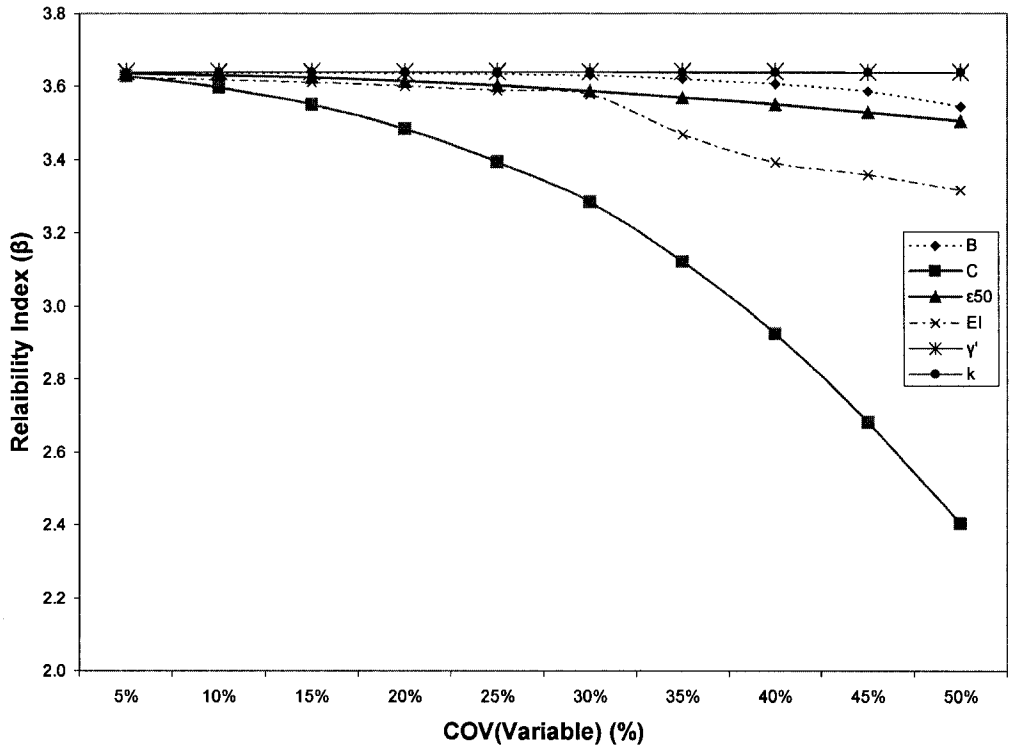

Fig. F.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single long pile (10T) at 250 kN lateral load.

For lateral load 305.25 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.008 \text{ m}$$

Table F.28 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 305.25kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	1.60E-09	6.76E-06	3.08	7.02E-08	6.83E-06	3.06
10%	6.76E-06	8.10E-09	6.77E-06	3.08	2.86E-07	7.05E-06	3.01
15%	6.76E-06	1.96E-08	6.78E-06	3.07	7.06E-07	7.47E-06	2.93
20%	6.76E-06	5.06E-08	6.81E-06	3.07	1.50E-06	8.26E-06	2.78
25%	6.76E-06	9.00E-08	6.85E-06	3.06	2.53E-06	9.29E-06	2.62
30%	6.76E-06	1.48E-07	6.91E-06	3.04	4.16E-06	1.09E-05	2.42
35%	6.76E-06	2.65E-07	7.03E-06	3.02	6.58E-06	1.33E-05	2.19
40%	6.76E-06	6.08E-07	7.37E-06	2.95	1.04E-05	1.71E-05	1.93
45%	6.76E-06	1.38E-06	8.14E-06	2.80	1.66E-05	2.34E-05	1.65
50%	6.76E-06	5.93E-06	1.27E-05	2.25	2.85E-05	3.52E-05	1.35

Table F.29 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 305.25 kN.

		ε50			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	7.22E-09	6.77E-06	3.08	1.12E-07	6.87E-06	3.05
10%	6.76E-06	3.06E-08	6.79E-06	3.07	1.68E-07	6.93E-06	3.04
15%	6.76E-06	6.76E-08	6.83E-06	3.06	2.35E-07	7.00E-06	3.02
20%	6.76E-06	1.23E-07	6.88E-06	3.05	3.19E-07	7.08E-06	3.01
25%	6.76E-06	1.89E-07	6.95E-06	3.03	4.16E-07	7.18E-06	2.99
30%	6.76E-06	2.70E-07	7.03E-06	3.02	5.33E-07	7.29E-06	2.96
35%	6.76E-06	3.72E-07	7.13E-06	3.00	1.55E-06	8.31E-06	2.78
40%	6.76E-06	4.83E-07	7.24E-06	2.97	2.30E-06	9.06E-06	2.66
45%	6.76E-06	6.08E-07	7.37E-06	2.95	2.67E-06	9.43E-06	2.60
50%	6.76E-06	7.57E-07	7.52E-06	2.92	3.12E-06	9.88E-06	2.55

Table F.30 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 305.25 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
10%	6.76E-06	2.50E-11	6.76E-06	3.08	4.00E-10	6.76E-06	3.08
15%	6.76E-06	2.50E-11	6.76E-06	3.08	9.00E-10	6.76E-06	3.08
20%	6.76E-06	2.50E-11	6.76E-06	3.08	2.02E-09	6.76E-06	3.08
25%	6.76E-06	1.00E-10	6.76E-06	3.08	3.02E-09	6.76E-06	3.08
30%	6.76E-06	1.00E-10	6.76E-06	3.08	2.02E-09	6.76E-06	3.08
35%	6.76E-06	1.00E-10	6.76E-06	3.08	3.02E-09	6.76E-06	3.08
40%	6.76E-06	2.25E-10	6.76E-06	3.08	3.60E-09	6.76E-06	3.08
45%	6.76E-06	2.25E-10	6.76E-06	3.08	5.63E-09	6.77E-06	3.08
50%	6.76E-06	2.25E-10	6.76E-06	3.08	7.23E-09	6.77E-06	3.08

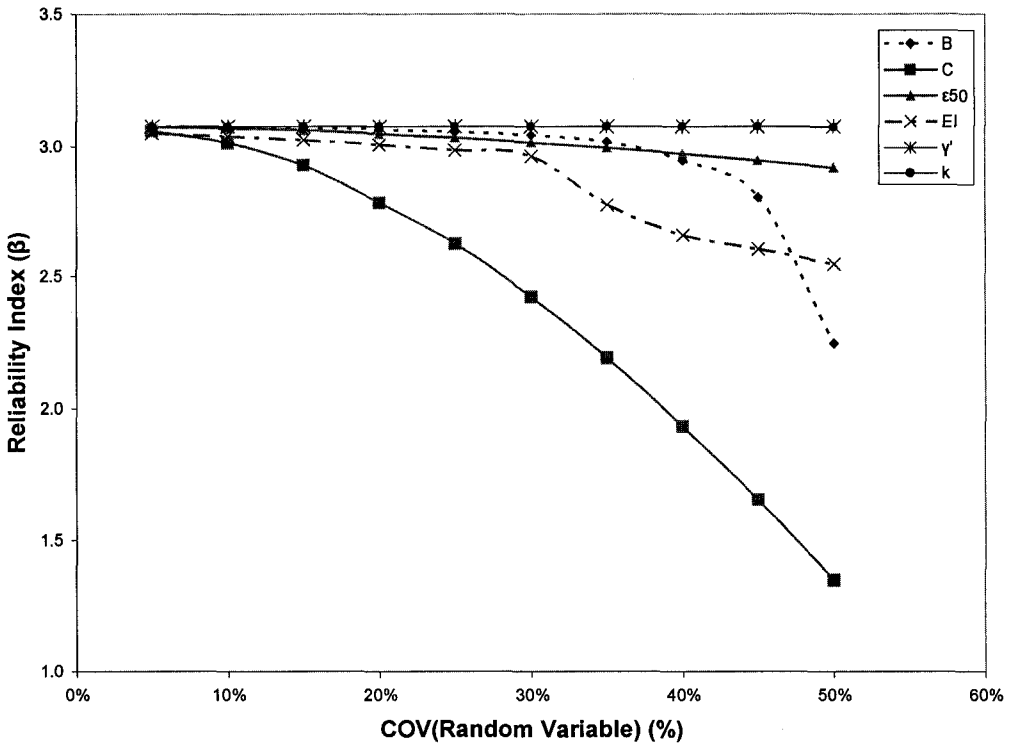

Fig. F.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single long pile (10T) at 305.25 kN lateral load.

For lateral load 340 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00697 \text{ m}$$

Table F.31 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 340 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	4.22E-09	6.76E-06	2.68	1.09E-07	6.87E-06	2.66
10%	6.76E-06	1.82E-08	6.78E-06	2.68	5.70E-07	7.33E-06	2.57
15%	6.76E-06	4.20E-08	6.80E-06	2.67	1.30E-06	8.06E-06	2.46
20%	6.76E-06	9.30E-08	6.85E-06	2.66	2.56E-06	9.32E-06	2.28
25%	6.76E-06	2.60E-07	7.02E-06	2.63	4.62E-06	1.14E-05	2.07
30%	6.76E-06	5.04E-07	7.26E-06	2.59	7.56E-06	1.43E-05	1.84
35%	6.76E-06	1.06E-06	7.82E-06	2.49	1.25E-05	1.93E-05	1.59
40%	6.76E-06	2.59E-06	9.35E-06	2.28	2.09E-05	2.77E-05	1.32
45%	6.76E-06	Failed	Failed	Failed	3.72E-05	4.40E-05	1.05
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table F.32 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 340 kN.

		ε50			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	9.02E-09	6.77E-06	2.68	1.52E-07	6.91E-06	2.65
10%	6.76E-06	3.61E-08	6.80E-06	2.67	2.35E-07	7.00E-06	2.64
15%	6.76E-06	8.41E-08	6.84E-06	2.66	3.31E-07	7.09E-06	2.62
20%	6.76E-06	1.48E-07	6.91E-06	2.65	4.90E-07	7.25E-06	2.59
25%	6.76E-06	2.35E-07	7.00E-06	2.64	6.72E-07	7.43E-06	2.56
30%	6.76E-06	3.36E-07	7.10E-06	2.62	8.46E-07	7.61E-06	2.53
35%	6.76E-06	4.62E-07	7.22E-06	2.59	2.72E-06	9.48E-06	2.26
40%	6.76E-06	6.01E-07	7.36E-06	2.57	3.98E-06	1.07E-05	2.13
45%	6.76E-06	7.57E-07	7.52E-06	2.54	4.62E-06	1.14E-05	2.07
50%	6.76E-06	9.31E-07	7.69E-06	2.51	5.59E-06	1.24E-05	1.98

Table F.33 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 340 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.68	2.25E-10	6.76E-06	2.68
10%	6.76E-06	2.50E-11	6.76E-06	2.68	9.00E-10	6.76E-06	2.68
15%	6.76E-06	2.50E-11	6.76E-06	2.68	2.03E-09	6.76E-06	2.68
20%	6.76E-06	1.00E-10	6.76E-06	2.68	3.60E-09	6.76E-06	2.68
25%	6.76E-06	1.00E-10	6.76E-06	2.68	5.63E-09	6.77E-06	2.68
30%	6.76E-06	1.00E-10	6.76E-06	2.68	9.02E-09	6.77E-06	2.68
35%	6.76E-06	2.25E-10	6.76E-06	2.68	1.21E-08	6.77E-06	2.68
40%	6.76E-06	2.25E-10	6.76E-06	2.68	1.69E-08	6.78E-06	2.68
45%	6.76E-06	4.00E-10	6.76E-06	2.68	1.00E-08	6.77E-06	2.68
50%	6.76E-06	4.00E-10	6.76E-06	2.68	1.00E-08	6.77E-06	2.68

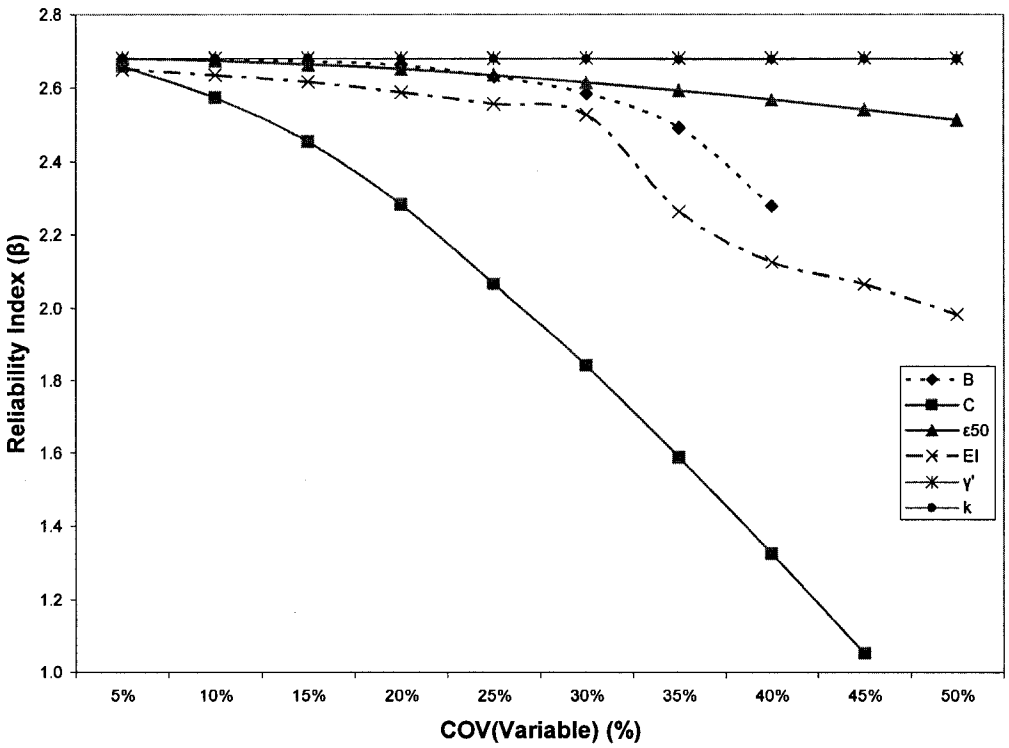

Fig. F.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single long pile (3T) at 340 kN lateral load.

For lateral load 375 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00563 \text{ m}$$

Table F.34 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 375 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	3.06E-08	6.79E-06	2.16	2.76E-07	7.04E-06	2.12
10%	6.76E-06	8.70E-08	6.85E-06	2.15	1.05E-06	7.81E-06	2.01
15%	6.76E-06	2.12E-07	6.97E-06	2.13	2.48E-06	9.24E-06	1.85
20%	6.76E-06	4.23E-07	7.18E-06	2.10	4.86E-06	1.16E-05	1.65
25%	6.76E-06	8.74E-07	7.63E-06	2.04	8.61E-06	1.54E-05	1.44
30%	6.76E-06	1.85E-06	8.61E-06	1.92	1.50E-05	2.17E-05	1.21
35%	6.76E-06	5.18E-06	1.19E-05	1.63	2.58E-05	3.26E-05	0.99
40%	6.76E-06	Failed	Failed	Failed	5.45E-05	6.13E-05	0.72
45%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table F.35 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 375 kN.

		ε50			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	1.21E-08	6.77E-06	2.16	3.25E-07	7.08E-06	2.12
10%	6.76E-06	4.84E-08	6.81E-06	2.16	4.76E-07	7.24E-06	2.09
15%	6.76E-06	1.06E-07	6.87E-06	2.15	6.48E-07	7.41E-06	2.07
20%	6.76E-06	1.89E-07	6.95E-06	2.14	8.93E-07	7.65E-06	2.04
25%	6.76E-06	2.92E-07	7.05E-06	2.12	1.20E-06	7.96E-06	2.00
30%	6.76E-06	4.23E-07	7.18E-06	2.10	1.53E-06	8.29E-06	1.96
35%	6.76E-06	5.62E-07	7.32E-06	2.08	4.97E-06	1.17E-05	1.64
40%	6.76E-06	7.23E-07	7.48E-06	2.06	7.05E-06	1.38E-05	1.52
45%	6.76E-06	9.03E-07	7.66E-06	2.03	8.61E-06	1.54E-05	1.44
50%	6.76E-06	1.08E-06	7.84E-06	2.01	9.99E-06	1.67E-05	1.38

Table F.36 Reliability Index connected to Y_{Top} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 375 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.17	4.00E-10	6.76E-06	2.17
10%	6.76E-06	2.50E-11	6.76E-06	2.17	2.25E-10	6.76E-06	2.17
15%	6.76E-06	1.00E-10	6.76E-06	2.17	2.50E-11	6.76E-06	2.17
20%	6.76E-06	1.00E-10	6.76E-06	2.17	6.25E-10	6.76E-06	2.17
25%	6.76E-06	1.00E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17
30%	6.76E-06	4.00E-10	6.76E-06	2.17	2.50E-11	6.76E-06	2.17
35%	6.76E-06	4.00E-10	6.76E-06	2.17	6.25E-10	6.76E-06	2.17
40%	6.76E-06	6.25E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17
45%	6.76E-06	9.00E-10	6.76E-06	2.17	9.00E-10	6.76E-06	2.17
50%	6.76E-06	9.00E-10	6.76E-06	2.17	3.60E-09	6.76E-06	2.16

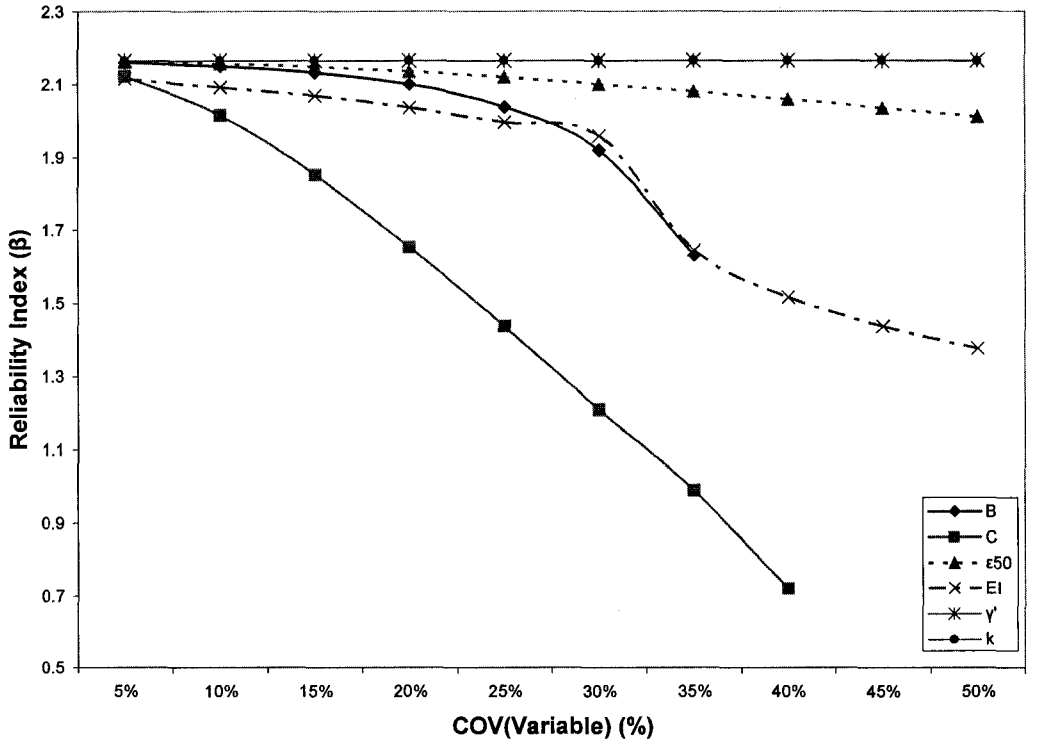

Fig. F.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head single long pile (10T) at 375 kN lateral load.

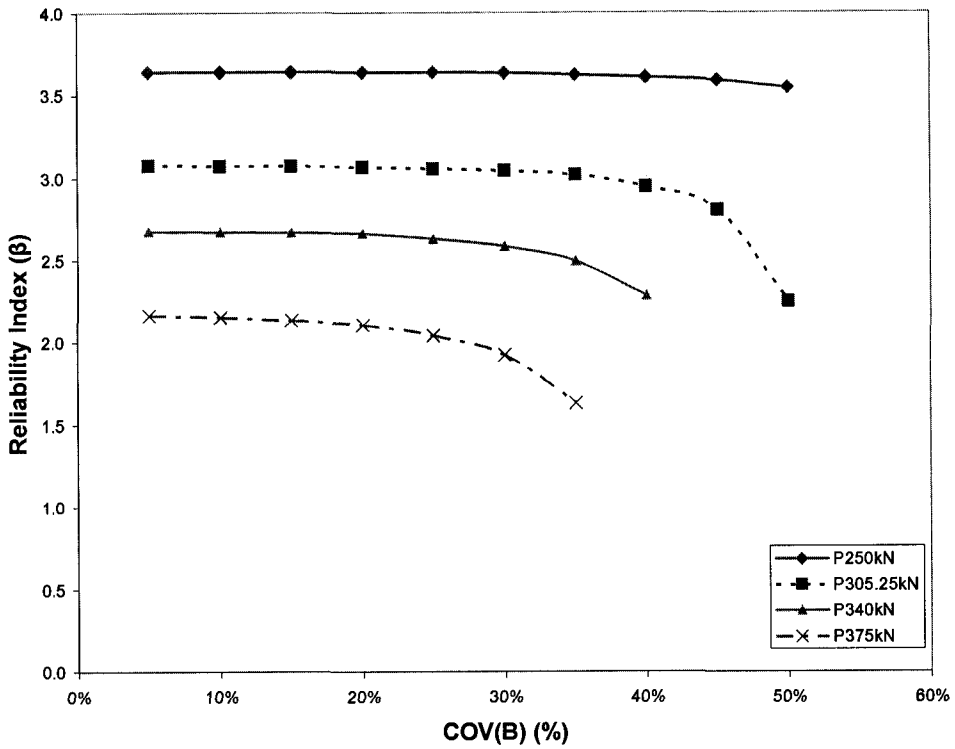

Fig. F.17 Reliability Index related to Y_{Top} for fixed head long pile with varying 'B'.

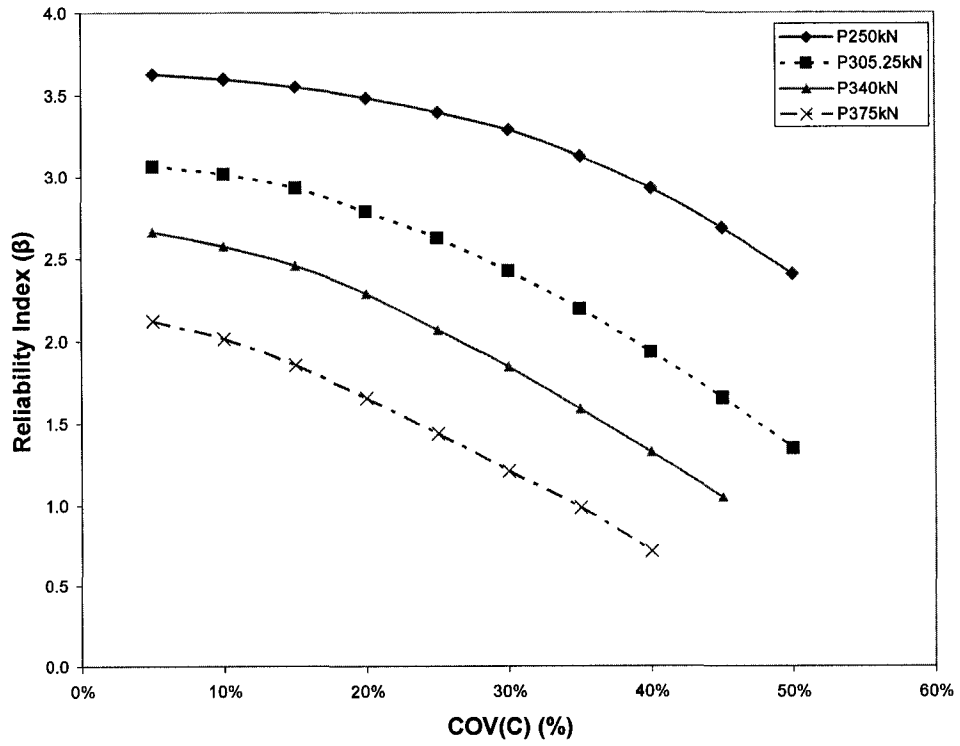

Fig.F.18 Reliability Index related to Y_{Top} for fixed head long pile with varying 'C'.

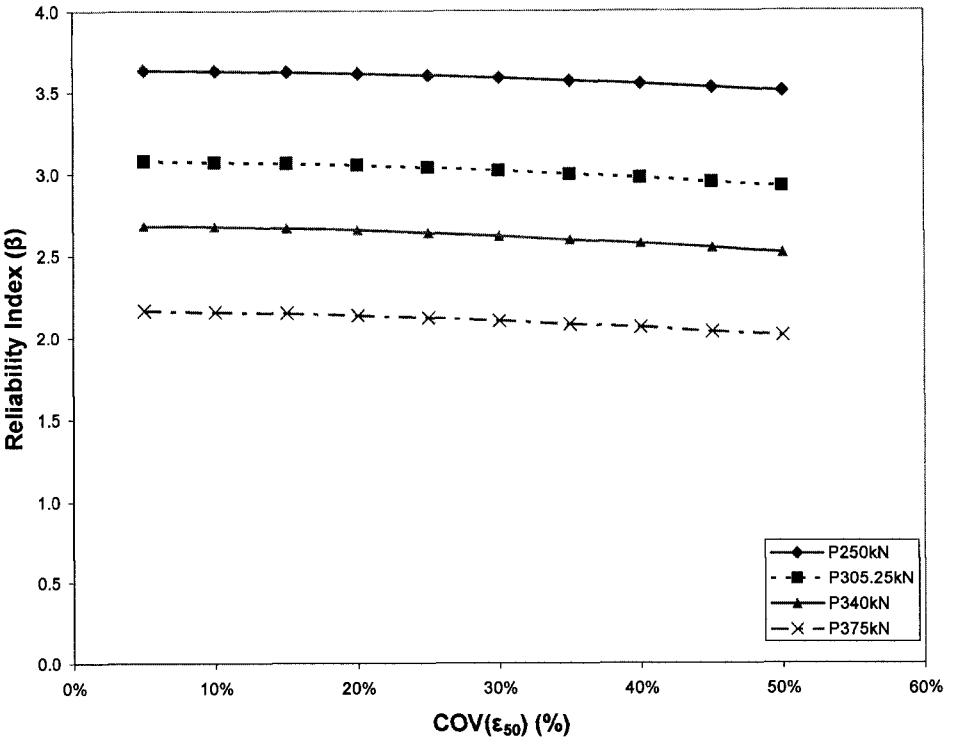

Fig. F.19 Reliability Index related to Y_{Top} for fixed head long pile with varying 'ε_{50}'.

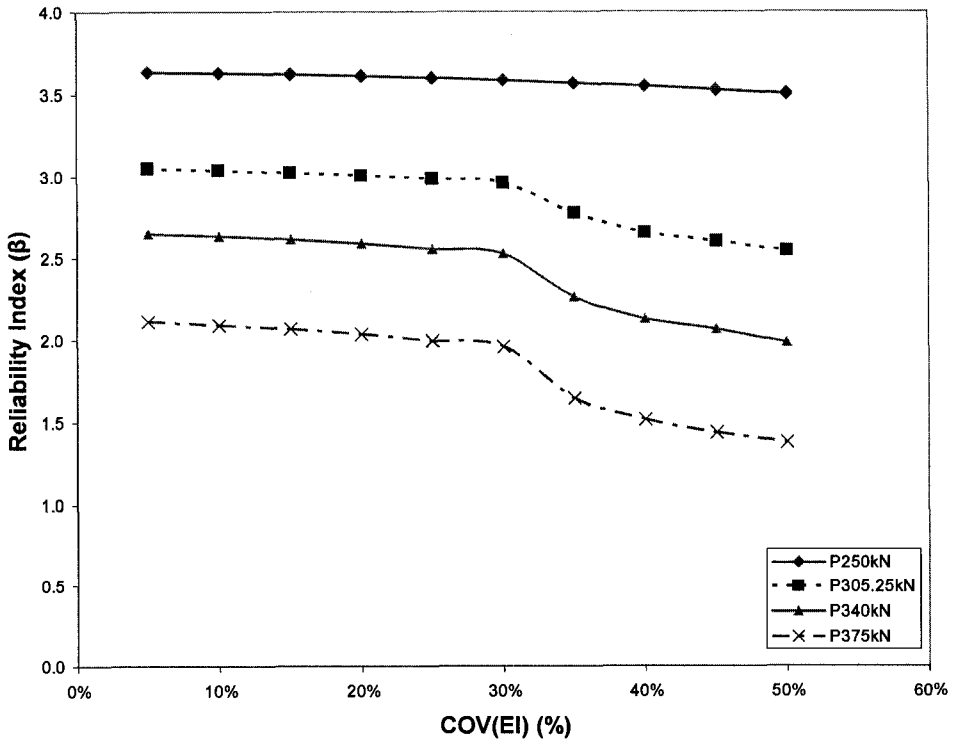

Fig. F.20 Reliability Index related to Y_{Top} for fixed head long pile with varying 'EI'.

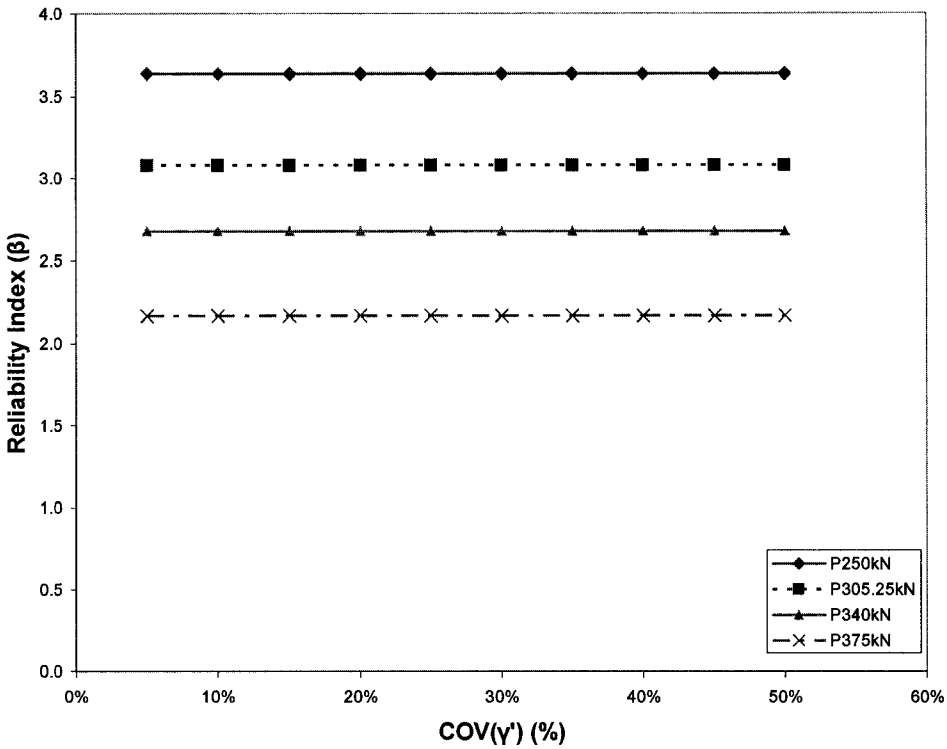

Fig. F.21 Reliability Index related to Y_{Top} for fixed head long pile with varying 'γ'.

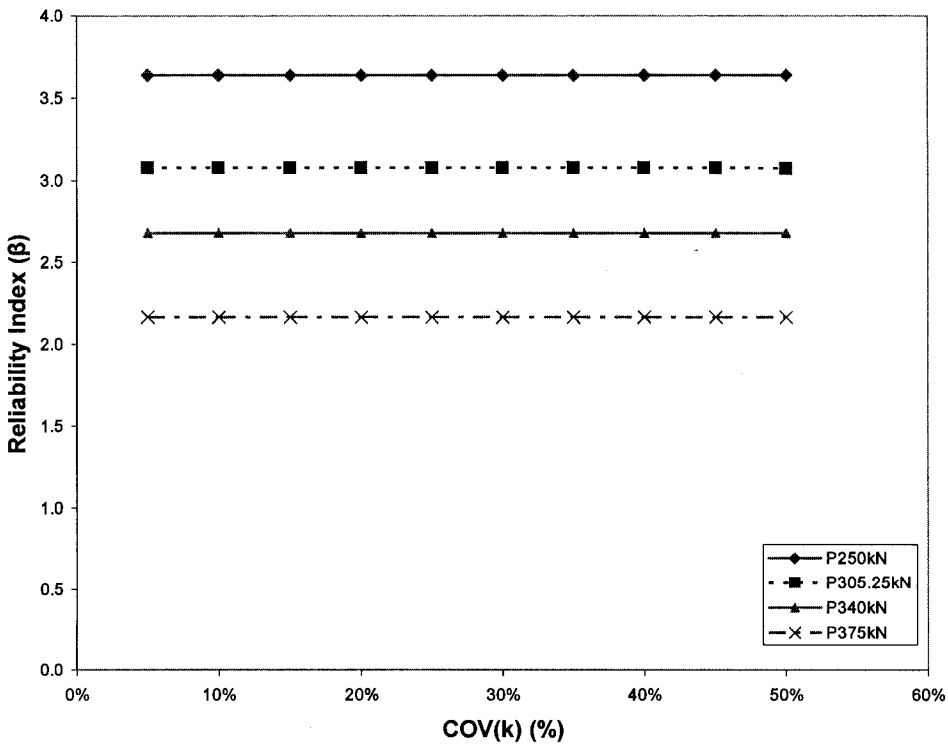

Fig. F.22 Reliability Index related to Y_{Top} for fixed head long pile with varying 'k'.

F.2.1 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 250 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 625 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table F.37 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 250 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) (kN-m)^2	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)
5%	31969.44	0.25	31969.69	3.50	30.25	31999.69	3.49
10%	31969.44	0.25	31969.69	3.50	100	32069.44	3.49
15%	31969.44	1	31970.44	3.50	225	32194.44	3.48
20%	31969.44	2.25	31971.69	3.50	400	32369.44	3.47
25%	31969.44	4	31973.44	3.50	650.25	32619.69	3.46
30%	31969.44	9	31978.44	3.50	961	32930.44	3.44
35%	31969.44	25	31994.44	3.49	1406.25	33375.69	3.42
40%	31969.44	42.25	32011.69	3.49	2025	33994.44	3.39
45%	31969.44	72.25	32041.69	3.49	2862.25	34831.69	3.35
50%	31969.44	132.25	32101.69	3.49	4032.25	36001.69	3.29

Table F.38 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 250 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	6.25	31975.69	3.50	16	31985.44	3.49
10%	31969.44	12.25	31981.69	3.49	20.25	31989.69	3.49
15%	31969.44	25	31994.44	3.49	30.25	31999.69	3.49
20%	31969.44	49	32018.44	3.49	42.25	32011.69	3.49
25%	31969.44	72.25	32041.69	3.49	56.25	32025.69	3.49
30%	31969.44	90.25	32059.69	3.49	72.25	32041.69	3.49
35%	31969.44	132.25	32101.69	3.49	169	32138.44	3.49
40%	31969.44	169	32138.44	3.49	289	32258.44	3.48
45%	31969.44	210.25	32179.69	3.48	306.25	32275.69	3.48
50%	31969.44	484	32453.44	3.47	361	32330.44	3.48

Table F.39 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 250 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.50	0.25	31969.69	3.50
10%	31969.44	0	31969.44	3.50	0.25	31969.69	3.50
15%	31969.44	0	31969.44	3.50	0.25	31969.69	3.50
20%	31969.44	0	31969.44	3.50	0.25	31969.69	3.50
25%	31969.44	0	31969.44	3.50	0	31969.44	3.50
30%	31969.44	0	31969.44	3.50	0	31969.44	3.50
35%	31969.44	0	31969.44	3.50	0	31969.44	3.50
40%	31969.44	0.25	31969.69	3.50	0.25	31969.69	3.50
45%	31969.44	1	31970.44	3.50	0.25	31969.69	3.50
50%	31969.44	1	31970.44	3.50	0.25	31969.69	3.50

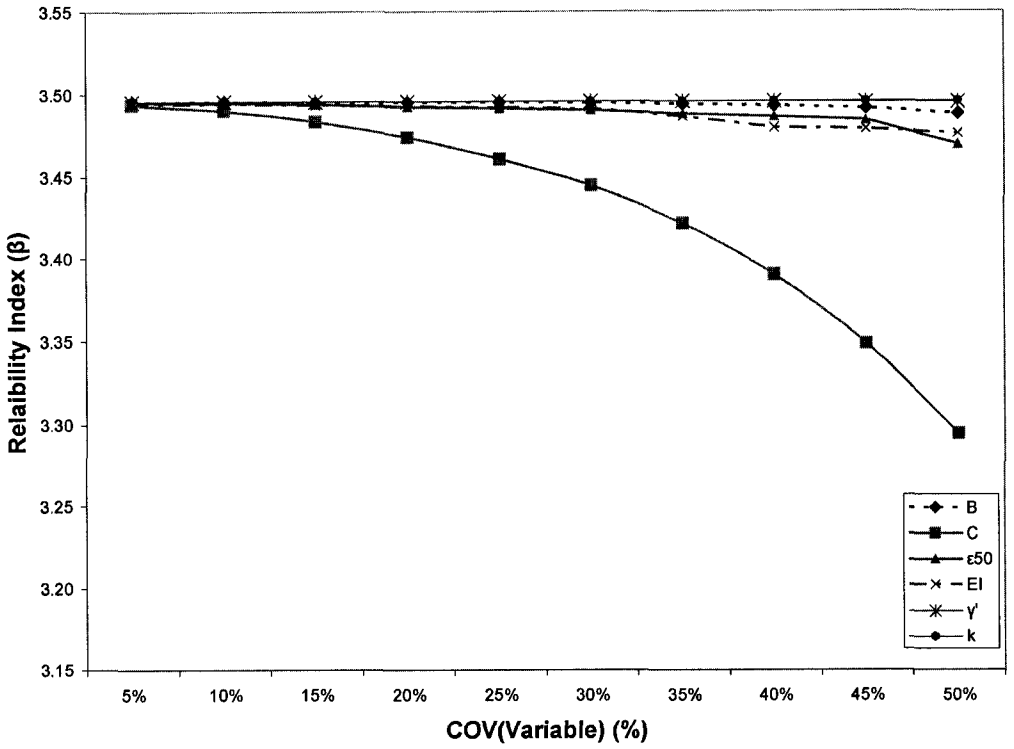

Fig. F.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single long pile (10T) at 250 kN lateral load.

For lateral load 305.25kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 547 \text{ kN.m}$$

Table F.40 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 305.25 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1	31970.44	3.06	42.25	32011.69	3.06
10%	31969.44	2.25	31971.69	3.06	169	32138.44	3.05
15%	31969.44	4	31973.44	3.06	420.25	32389.69	3.04
20%	31969.44	20.25	31989.69	3.06	812.25	32781.69	3.02
25%	31969.44	30.25	31999.69	3.06	1332.25	33301.69	3.00
30%	31969.44	49	32018.44	3.06	2070.25	34039.69	2.96
35%	31969.44	100	32069.44	3.05	3080.25	35049.69	2.92
40%	31969.44	225	32194.44	3.05	4556.25	36525.69	2.86
45%	31969.44	506.25	32475.69	3.04	6561	38530.44	2.79
50%	31969.44	2070.25	34039.69	2.96	9801	41770.44	2.68

Table F.41 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 305.25 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	4	31973.44	3.06	20.25	31989.69	3.06
10%	31969.44	9	31978.44	3.06	30.25	31999.69	3.06
15%	31969.44	25	31994.44	3.06	42.25	32011.69	3.06
20%	31969.44	42.25	32011.69	3.06	56.25	32025.69	3.06
25%	31969.44	64	32033.44	3.06	72.25	32041.69	3.06
30%	31969.44	90.25	32059.69	3.05	81	32050.44	3.06
35%	31969.44	132.25	32101.69	3.05	182.25	32151.69	3.05
40%	31969.44	156.25	32125.69	3.05	342.25	32311.69	3.04
45%	31969.44	210.25	32179.69	3.05	400	32369.44	3.04
50%	31969.44	256	32225.44	3.05	420.25	32389.69	3.04

Table F.42 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 305.25 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	3.06	0	31969.44	3.06
10%	31969.44	0	31969.44	3.06	0.25	31969.69	3.06
15%	31969.44	0	31969.44	3.06	1	31970.44	3.06
20%	31969.44	0	31969.44	3.06	1	31970.44	3.06
25%	31969.44	0	31969.44	3.06	1	31970.44	3.06
30%	31969.44	0.25	31969.69	3.06	1	31970.44	3.06
35%	31969.44	0.25	31969.69	3.06	1	31970.44	3.06
40%	31969.44	0.25	31969.69	3.06	1	31970.44	3.06
45%	31969.44	0.25	31969.69	3.06	2.25	31971.69	3.06
50%	31969.44	0.25	31969.69	3.06	4	31973.44	3.06

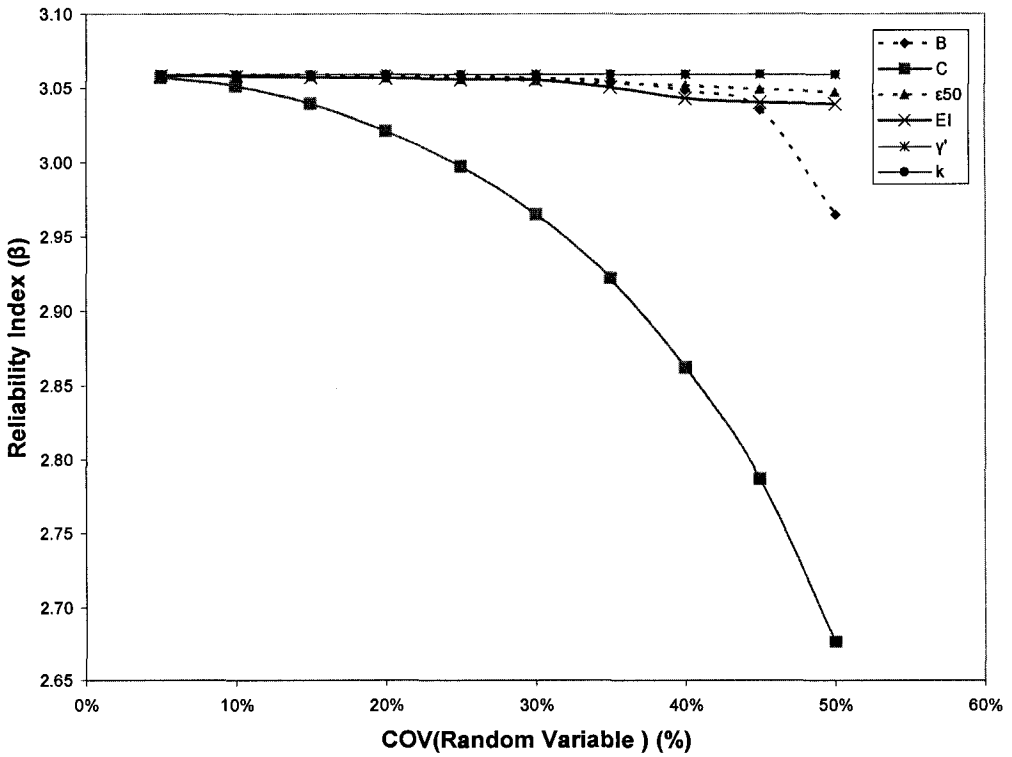

Fig. F.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single long pile (10T) at 305.25 kN lateral load.

For lateral load 340 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 495 \text{ kN.m}$$

Table F.43 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 340 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1	31970.44	2.77	56.25	32025.69	2.77
10%	31969.44	6.25	31975.69	2.77	289	32258.44	2.76
15%	31969.44	12.25	31981.69	2.77	650.25	32619.69	2.74
20%	31969.44	30.25	31999.69	2.77	1225	33194.44	2.72
25%	31969.44	81	32050.44	2.76	2162.25	34131.69	2.68
30%	31969.44	169	32138.44	2.76	3364	35333.44	2.63
35%	31969.44	361	32330.44	2.75	5041	37010.44	2.57
40%	31969.44	900	32869.44	2.73	7656.25	39625.69	2.49
45%	31969.44	Failed	Failed	Failed	12100	44069.44	2.36
50%	31969.44	Failed	Failed	Failed	206570.25	238539.69	1.01

Table F.44 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 340 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	4	31973.44	2.77	25	31994.44	2.77
10%	31969.44	9	31978.44	2.77	36	32005.44	2.77
15%	31969.44	25	31994.44	2.77	49	32018.44	2.77
20%	31969.44	42.25	32011.69	2.77	56.25	32025.69	2.77
25%	31969.44	64	32033.44	2.77	64	32033.44	2.77
30%	31969.44	90.25	32059.69	2.76	81	32050.44	2.76
35%	31969.44	132.25	32101.69	2.76	182.25	32151.69	2.76
40%	31969.44	156.25	32125.69	2.76	324	32293.44	2.75
45%	31969.44	210.25	32179.69	2.76	380.25	32349.69	2.75
50%	31969.44	240.25	32209.69	2.76	380.25	32349.69	2.75

Table F.45 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 340 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	2.77	0	31969.44	2.77
10%	31969.44	0	31969.44	2.77	1	31970.44	2.77
15%	31969.44	0	31969.44	2.77	1	31970.44	2.77
20%	31969.44	0	31969.44	2.77	1	31970.44	2.77
25%	31969.44	0	31969.44	2.77	2.25	31971.69	2.77
30%	31969.44	0	31969.44	2.77	4	31973.44	2.77
35%	31969.44	0	31969.44	2.77	6.25	31975.69	2.77
40%	31969.44	0	31969.44	2.77	6.25	31975.69	2.77
45%	31969.44	1	31970.44	2.77	4	31973.44	2.77
50%	31969.44	1	31970.44	2.77	4	31973.44	2.77

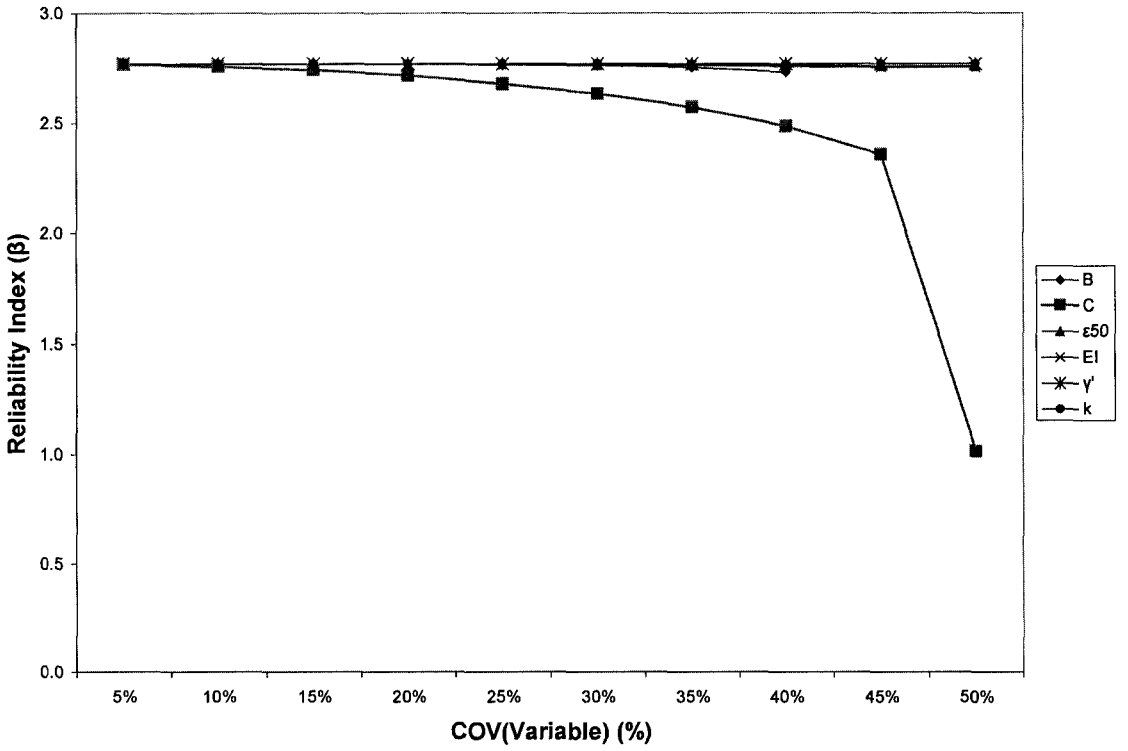

Fig. F.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single long pile (10T) at 340 kN lateral load.

For lateral load 375 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 437 \text{ kN.m}$$

Table F.46 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'B' and 'C' and applied lateral load 375 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	9	31978.44	2.44	132.25	32101.69	2.44
10%	31969.44	25	31994.44	2.44	484	32453.44	2.43
15%	31969.44	64	32033.44	2.44	1089	33058.44	2.40
20%	31969.44	132.25	32101.69	2.44	2025	33994.44	2.37
25%	31969.44	289	32258.44	2.43	3422.25	35391.69	2.32
30%	31969.44	600.25	32569.69	2.42	5625	37594.44	2.25
35%	31969.44	1722.25	33691.69	2.38	8930.25	40899.69	2.16
40%	31969.44	Failed	Failed	Failed	16002.25	47971.69	2.00
45%	31969.44	Failed	Failed	Failed	38416	70385.44	1.65
50%	31969.44	Failed	Failed	Failed	37442.25	69411.69	1.66

Table F.47 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'ε_{50}' and 'EI' and applied lateral load 375 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	4	31973.44	2.44	16	31985.44	2.44
10%	31969.44	9	31978.44	2.44	25	31994.44	2.44
15%	31969.44	25	31994.44	2.44	36	32005.44	2.44
20%	31969.44	36	32005.44	2.44	42.25	32011.69	2.44
25%	31969.44	64	32033.44	2.44	49	32018.44	2.44
30%	31969.44	81	32050.44	2.44	72.25	32041.69	2.44
35%	31969.44	110.25	32079.69	2.44	110.25	32079.69	2.44
40%	31969.44	132.25	32101.69	2.44	240.25	32209.69	2.43
45%	31969.44	169	32138.44	2.44	256	32225.44	2.43
50%	31969.44	182.25	32151.69	2.44	272.25	32241.69	2.43

Table F.48 Reliability Index connected to M_{Max} for fixed head single long pile (10T) with varying 'γ'' and 'k' and applied lateral load 375 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	2.44	0.25	31969.69	2.44
10%	31969.44	0	31969.44	2.44	0.25	31969.69	2.44
15%	31969.44	0	31969.44	2.44	0.25	31969.69	2.44
20%	31969.44	0	31969.44	2.44	0	31969.44	2.44
25%	31969.44	0	31969.44	2.44	0	31969.44	2.44
30%	31969.44	0	31969.44	2.44	0.25	31969.69	2.44
35%	31969.44	0	31969.44	2.44	0.25	31969.69	2.44
40%	31969.44	0.25	31969.69	2.44	0.25	31969.69	2.44
45%	31969.44	1	31970.44	2.44	1	31970.44	2.44
50%	31969.44	1	31970.44	2.44	2.25	31971.69	2.44

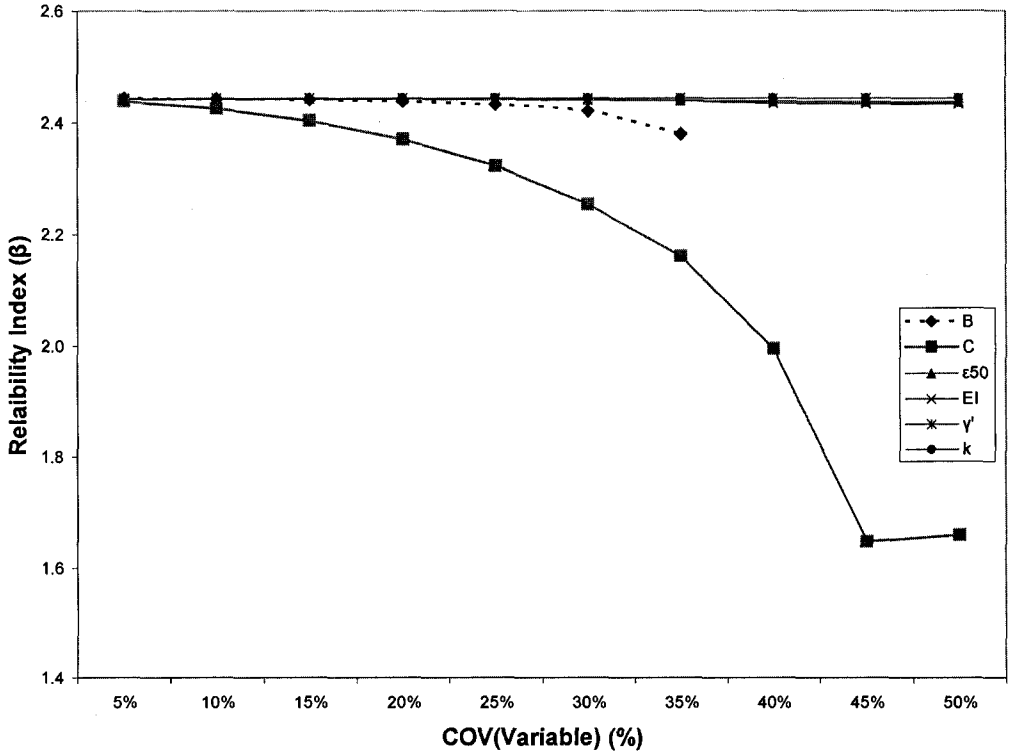

Fig. F.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in fixed head single long pile (10T) at 375 kN lateral load.

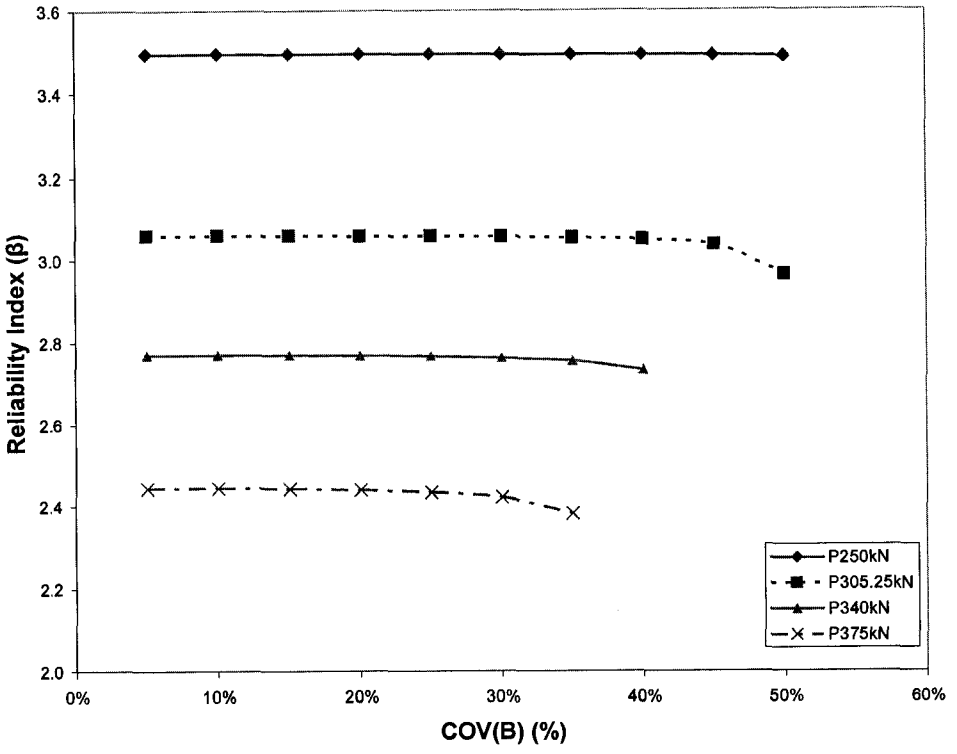

Fig. F.27 Reliability Index related to M_{Max} for fixed head long pile with varying 'B'.

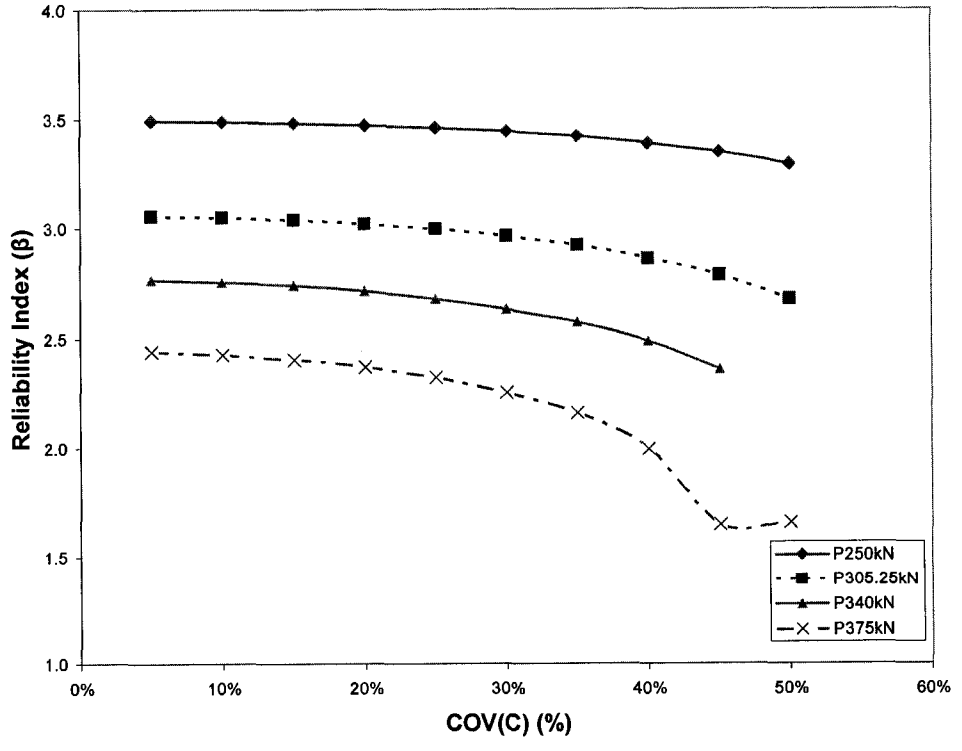

Fig. F.28 Reliability Index related to M_{Max} for fixed head long pile with varying 'C'.

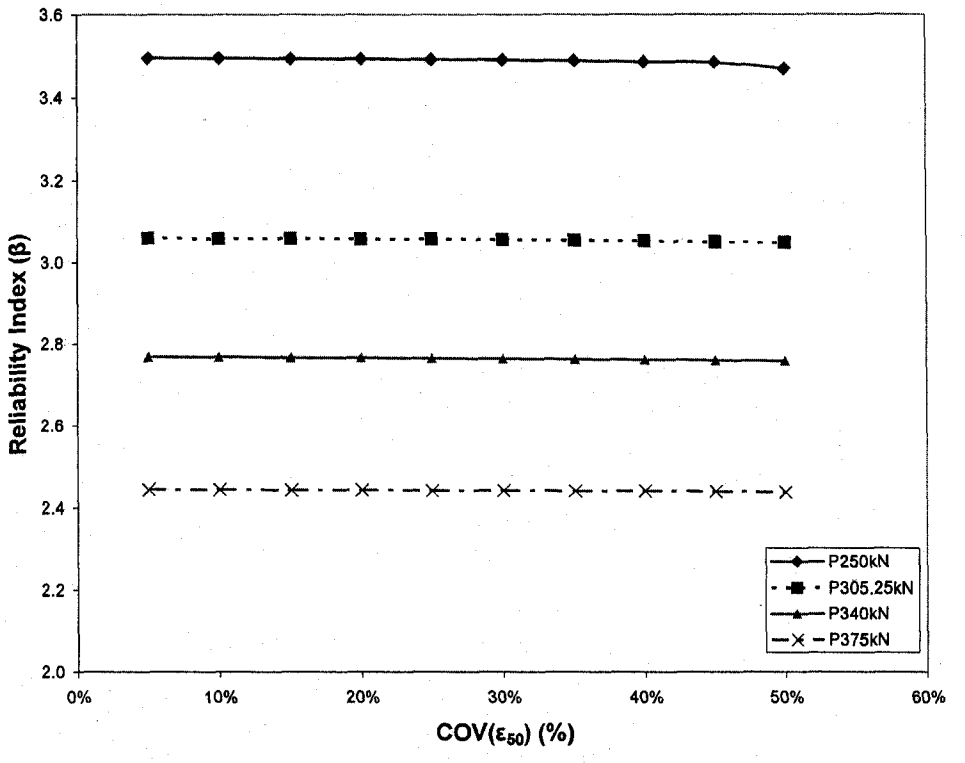

Fig. F.29 Reliability Index related to M_{Max} for fixed head long pile with varying 'ε_{50}'

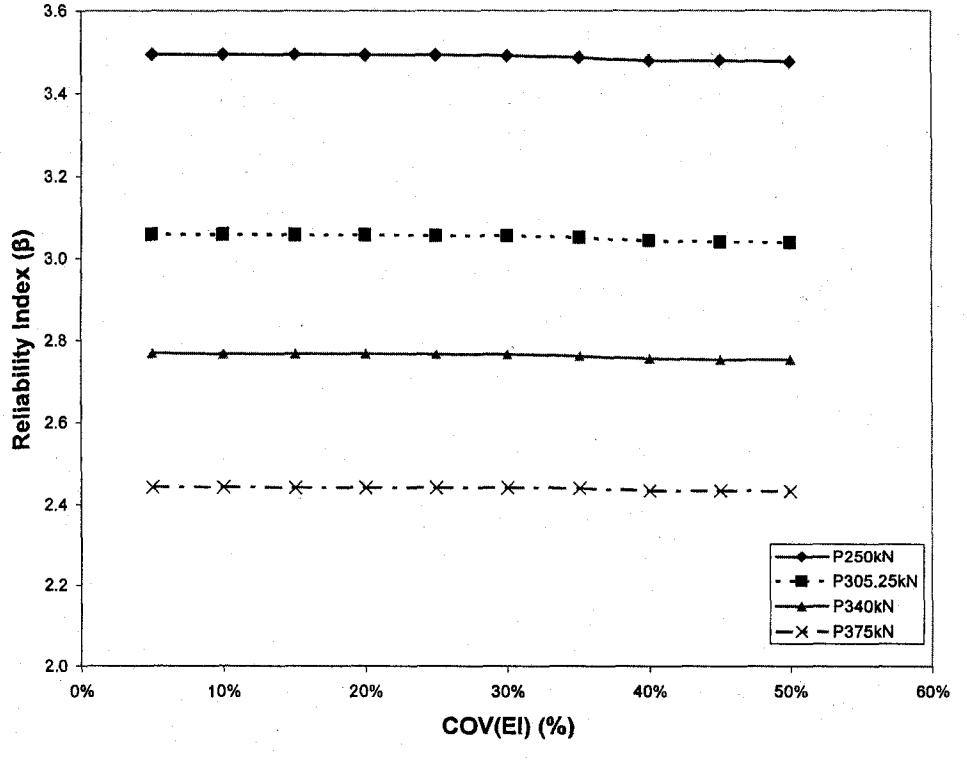

Fig. F.30 Reliability Index related to M_{Max} for fixed head long pile with varying 'EI'

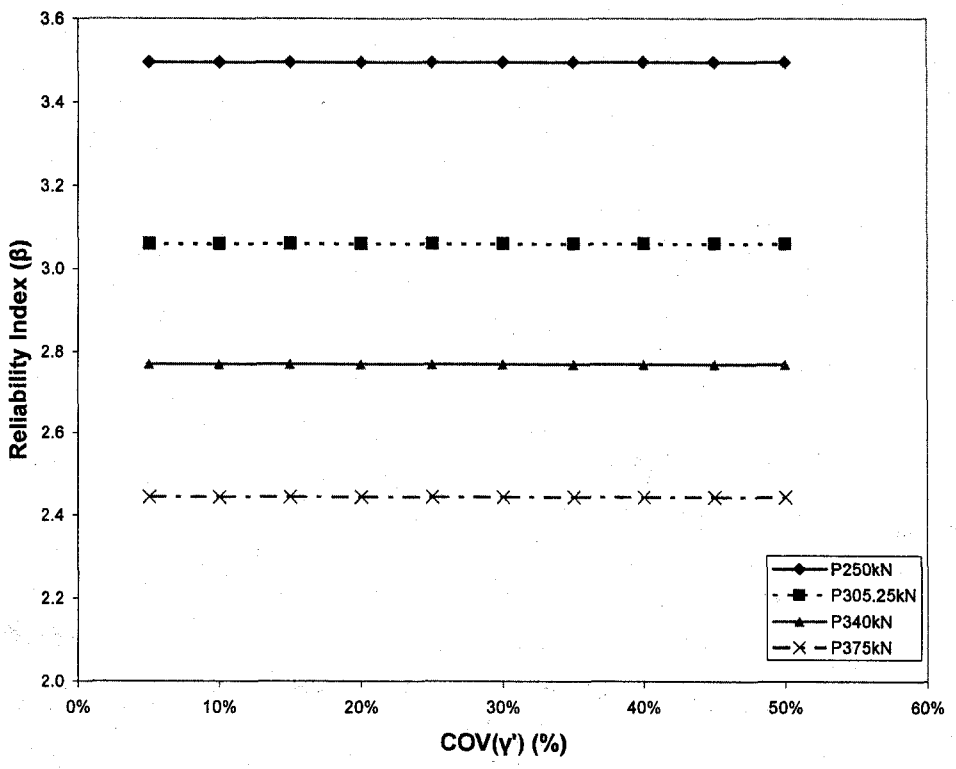

Fig. F.31 Reliability Index related to M_{Max} for fixed head long pile with varying 'γ''.

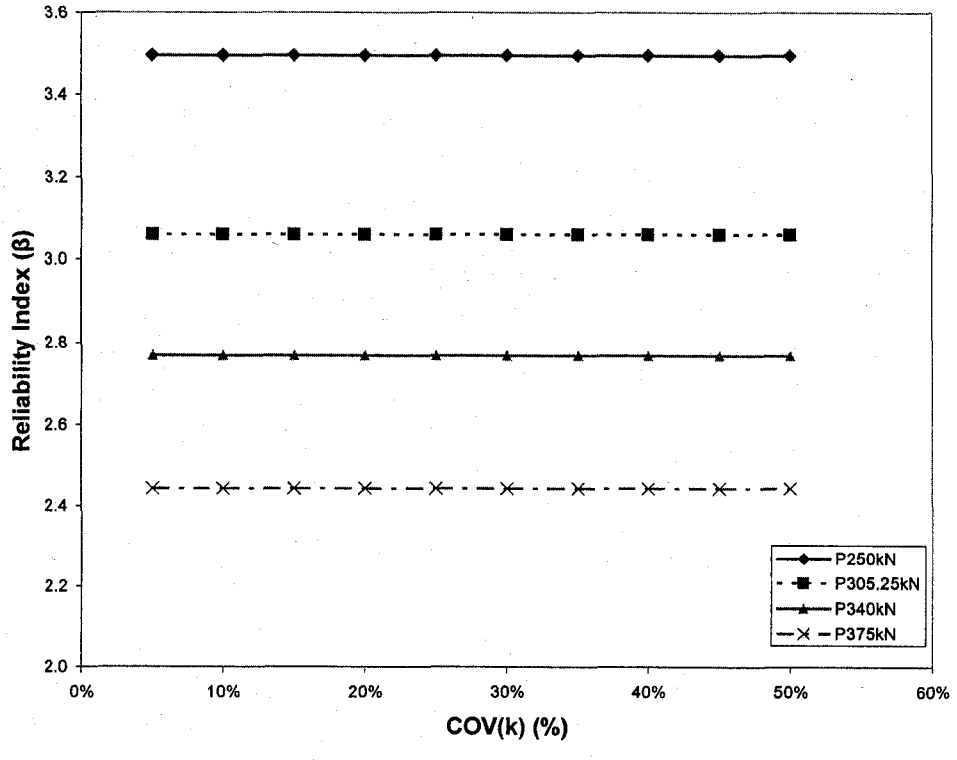

Fig. F.32 Reliability Index related to M_{Max} for fixed head long pile with varying 'k'.

RELIABILITY ANALYSIS OF NON-LINEAR (p-y) LATERALLY LOADED PILES EMBEDDED IN STIFF CLAY BELOW WATER TABLE

(Volume 2)

BY

SHAILENDRASINH JADEJA

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APPENDIX G

LATERALLY LOADED HINGED HEAD LONG PILE GROUP

(Spacing: 3D)

G.1.1 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (3D) and with 'B' as varying random design variable

Table G.1. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 589 kN and 817 kN.

			P=589 kN (59, 65, 72 kN)				P=817 kN (82, 90, 100 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	0.00366	74.83	82.9	93.84	0.00649	105.1	114.8	131.1
45%	0.052258	0.2794	0.00345	75.08	82.92	93.58	0.00596	103.3	114.8	130.8
40%	0.0412902	0.3048	0.00332	75.4	82.97	93.21	0.00559	103.4	114.9	130.6
35%	0.0316128	0.3302	0.00321	75.53	82.98	93.07	0.00528	103.7	114.9	130.4
30%	0.0232258	0.3556	0.00312	75.63	83.03	92.92	0.00503	103.8	115	130.1
25%	0.016129	0.381	0.00303	75.72	83.05	92.82	0.00482	104.1	115	129.9
20%	0.0103226	0.4064	0.00296	75.82	82.99	92.77	0.00465	104.4	115.1	129.5
15%	0.0058064	0.4318	0.00298	75.85	83	92.74	0.00469	104.5	115.1	129.3
10%	0.0025806	0.4572	0.00301	75.88	83	92.7	0.00473	104.7	115.1	129.2
5%	0.0006452	0.4826	0.00302	75.92	83	92.66	0.00474	104.7	115.1	129.2
0%	0	0.508	0.00302	75.88	83	92.7	0.00474	104.7	115.1	129.2
5%	0.0006452	0.5334	0.00308	76	83	92.58	0.00482	104.8	115.1	129.1
10%	0.0025806	0.5588	0.0031	76.04	82.99	92.54	0.00485	104.8	115.1	129.1
15%	0.0058064	0.5842	0.00312	76.03	83.02	92.52	0.00487	104.8	115.1	129
20%	0.0103226	0.6096	0.00313	76.08	83.01	92.48	0.00489	104.9	115.1	128.9
25%	0.016129	0.635	0.00315	76.13	83	92.45	0.0049	104.9	115.1	128.9
30%	0.0232258	0.6604	0.00316	76.17	82.99	92.41	0.00491	105	115.1	128.8
35%	0.0316128	0.6858	0.00316	76.22	82.98	92.37	0.00492	105	115.1	128.8
40%	0.0412902	0.7112	0.00317	76.27	82.97	92.33	0.00493	105.1	115.1	128.7
45%	0.052258	0.7366	0.00317	76.3	82.96	92.31	0.00493	105.1	115.1	128.7
50%	0.064516	0.762	0.00318	76.33	82.96	92.28	0.00493	105.2	115.1	128.6

Table G.2 Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 953 kN and 1142 kN.

			P=953 kN(95, 100, 120 kN)				**P=1142 kN**(110,130,140 kN)			
			Ytop (m)	**Mmax (kN-m)**			**Ytop (m)**	**Mmax (kN-m)**		
COV(B) (%)	**Var (B) (m)2**	**Bcurrent (m)**	**A/B/C**	**A**	**B**	**C**	**A/B/C**	**A**	**B**	**C**
50%	0.064516	0.254	0.00889	133.9	142.8	153.7	0.017	200.4	218.2	240.4
45%	0.052258	0.2794	0.00797	126.2	133.9	153	0.0121	171.2	182.5	198.4
40%	0.0412902	0.3048	0.00735	120.7	133.9	152.8	0.0106	159.7	170.3	183.7
35%	0.0316128	0.3302	0.00686	120.5	134	152.5	0.00966	152.2	161.6	183.4
30%	0.0232258	0.3556	0.00648	120.7	134	152.3	0.00899	146.3	160.4	183.2
25%	0.016129	0.381	0.00619	120.9	134	152.1	0.00848	144.3	160.5	182.9
20%	0.0103226	0.4064	0.00593	121.1	134	151.9	0.00805	144.5	160.6	182.6
15%	0.0058064	0.4318	0.00595	121.2	134.1	151.7	0.00803	144.7	160.6	182.5
10%	0.0025806	0.4572	0.00597	121.3	134.1	151.6	0.00804	144.8	160.6	182.3
5%	0.0006452	0.4826	0.00595	121.4	134.1	151.5	0.00804	145	160.6	182.1
0%	0	0.508	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
5%	0.0006452	0.5334	0.00602	121.6	134.1	151.3	0.00803	145.2	160.7	181.9
10%	0.0025806	0.5588	0.00603	121.7	134.2	151.2	0.00805	145.3	160.7	181.7
15%	0.0058064	0.5842	0.00605	121.9	134.2	151	0.00803	145.5	160.7	181.6
20%	0.0103226	0.6096	0.00606	122	134.3	150.7	0.00802	145.6	160.7	181.5
25%	0.016129	0.635	0.00607	122.2	134.2	150.6	0.008	145.7	160.7	181.4
30%	0.0232258	0.6604	0.00607	122.3	134.2	150.5	0.00799	145.8	160.7	181.2
35%	0.0316128	0.6858	0.00608	122.4	134.2	150.4	0.00797	145.9	160.7	181.1
40%	0.0412902	0.7112	0.0061	122.4	134.2	150.4	0.00795	146	160.7	181
45%	0.052258	0.7366	0.0061	122.5	134.2	150.3	0.00794	146.1	160.8	180.9
50%	0.064516	0.762	0.0061	122.5	134.2	150.2	0.00791	146.4	160.8	180.8

Note: The digits in bracket beside the lateral load, shows the load distribution in rows of pile. For example, in **953 kN** (95, 100, 120 kN), 953 kN is an lateral load and 95, 100, and 120 kN are load distribution on pile rows A, B, C respectively.

Table G.3(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 589 kN and 817 kN.

		P=589 kN		P=817 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	9.00E-10	0.993%	1.60E-09	0.844%
10%	2.58E-03	2.02E-09	1.490%	3.60E-09	1.266%
15%	5.81E-03	4.90E-09	2.318%	8.10E-09	1.899%
20%	1.03E-02	7.23E-09	2.815%	1.44E-08	2.532%
25%	1.61E-02	3.60E-09	1.987%	1.60E-09	0.844%
30%	2.32E-02	4.00E-10	0.662%	3.60E-09	1.266%
35%	3.16E-02	6.25E-10	0.828%	3.24E-08	3.797%
40%	4.13E-02	5.63E-09	2.483%	1.09E-07	6.962%
45%	5.23E-02	1.96E-08	4.636%	2.65E-07	10.865%
50%	6.45E-02	5.76E-08	7.947%	6.08E-07	16.456%

Table G.3(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (3D) and with varying 'B' and lateral load 953 kN and 1142 kN.

		P=953 kN		P=1142 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	1.22E-09	0.588%	2.50E-11	0.063%
10%	2.58E-03	9.00E-10	0.504%	2.50E-11	0.063%
15%	5.81E-03	2.50E-09	0.840%	0.00E+00	0.000%
20%	1.03E-02	4.23E-09	1.092%	2.25E-10	0.188%
25%	1.61E-02	3.60E-09	1.008%	5.76E-08	3.011%
30%	2.32E-02	4.20E-08	3.445%	2.50E-07	6.274%
35%	3.16E-02	1.52E-07	6.555%	7.14E-07	10.602%
40%	4.13E-02	3.91E-07	10.504%	1.76E-06	16.625%
45%	5.23E-02	8.74E-07	15.714%	4.33E-06	26.098%
50%	6.45E-02	1.95E-06	23.445%	2.07E-05	57.026%

Table G.4(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 589 kN.

		P=589 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.00064516	0.0016	0.00	0.0016	0.05%	0.00%	0.04%
10%	0.00258064	0.0064	0.00	0.0064	0.11%	0.01%	0.09%
15%	0.00580644	0.0081	0.00	0.0121	0.12%	0.01%	0.12%
20%	0.01032256	0.0169	0.00	0.02102	0.17%	0.01%	0.16%
25%	0.016129	0.04202	0.00	0.01369	0.27%	0.03%	0.13%
30%	0.02322576	0.0729	0.00	0.06503	0.36%	0.02%	0.28%
35%	0.03161284	0.11902	0.00	0.1225	0.45%	0.00%	0.38%
40%	0.04129024	0.18922	0.00	0.1936	0.57%	0.00%	0.47%
45%	0.05225796	0.3721	0.00	0.40322	0.80%	0.02%	0.69%
50%	0.064516	0.5625	0.00	0.6084	0.99%	0.04%	0.84%

Table G.4(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 817 kN.

		P=817 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.00064516	0.0025	0	0.0025	0.05%	0.00%	0.04%
10%	0.00258064	0.0025	0	0.0025	0.05%	0.00%	0.04%
15%	0.00580644	0.0225	0	0.0225	0.14%	0.00%	0.12%
20%	0.01032256	0.0625	0	0.09	0.24%	0.00%	0.23%
25%	0.016129	0.16	0.0025	0.25	0.38%	0.04%	0.39%
30%	0.02322576	0.36	0.0025	0.4225	0.57%	0.04%	0.50%
35%	0.03161284	0.4225	0.01	0.64	0.62%	0.09%	0.62%
40%	0.04129024	0.7225	0.01	0.9025	0.81%	0.09%	0.74%
45%	0.05225796	0.81	0.0225	1.1025	0.86%	0.13%	0.81%
50%	0.064516	0.0025	0.0225	1.5625	0.05%	0.13%	0.97%

Table G.4(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 953 kN.

		P=953 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.00064516	0.01	0	0.01	0.08%	0.00%	0.07%
10%	0.00258064	0.04	0.0025	0.04	0.16%	0.04%	0.13%
15%	0.00580644	0.1225	0.0025	0.1225	0.29%	0.04%	0.23%
20%	0.01032256	0.2025	0.0225	0.36	0.37%	0.11%	0.40%
25%	0.016129	0.4225	0.01	0.5625	0.54%	0.07%	0.50%
30%	0.02322576	0.64	0.01	0.81	0.66%	0.07%	0.59%
35%	0.03161284	0.9025	0.01	1.1025	0.78%	0.07%	0.69%
40%	0.04129024	0.7225	0.0225	1.44	0.70%	0.11%	0.79%
45%	0.05225796	3.4225	0.0225	1.8225	1.52%	0.11%	0.89%
50%	0.064516	32.49	18.49	3.0625	4.70%	3.21%	1.16%

Table G.4(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 1142 kN.

		P=1142 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.00064516	0.01	0.0025	0.01	0.07%	0.03%	0.05%
10%	0.00258064	0.0625	0.0025	0.09	0.17%	0.03%	0.16%
15%	0.00580644	0.16	0.0025	0.2025	0.28%	0.03%	0.25%
20%	0.01032256	0.3025	0.0025	0.3025	0.38%	0.03%	0.30%
25%	0.016129	0.49	0.01	0.5625	0.48%	0.06%	0.41%
30%	0.02322576	0.0625	0.0225	1	0.17%	0.09%	0.55%
35%	0.03161284	9.9225	0.2025	1.3225	2.17%	0.28%	0.63%
40%	0.04129024	46.9225	23.04	1.8225	4.72%	2.99%	0.74%
45%	0.05225796	157.503	117.723	76.5625	8.66%	6.76%	4.81%
50%	0.064516	729	823.69	888.04	18.6%	17.9%	16.4%

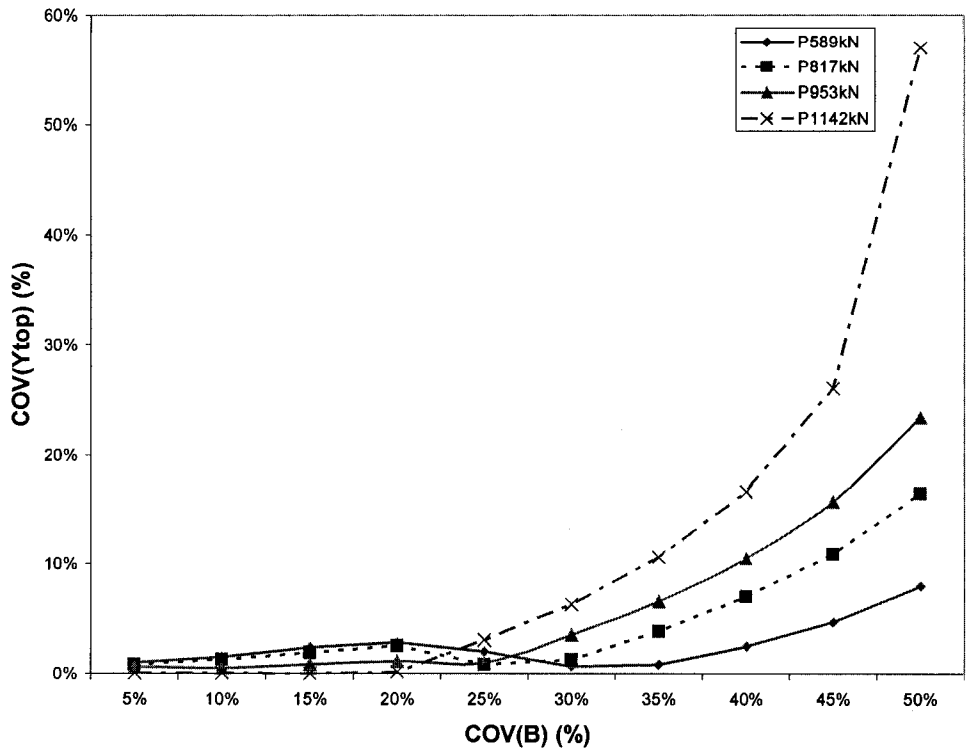

Fig. G.1 COV(Y_{Top}) for varying COV(B) in hinged head long (10T) pile group with spacing (3D).

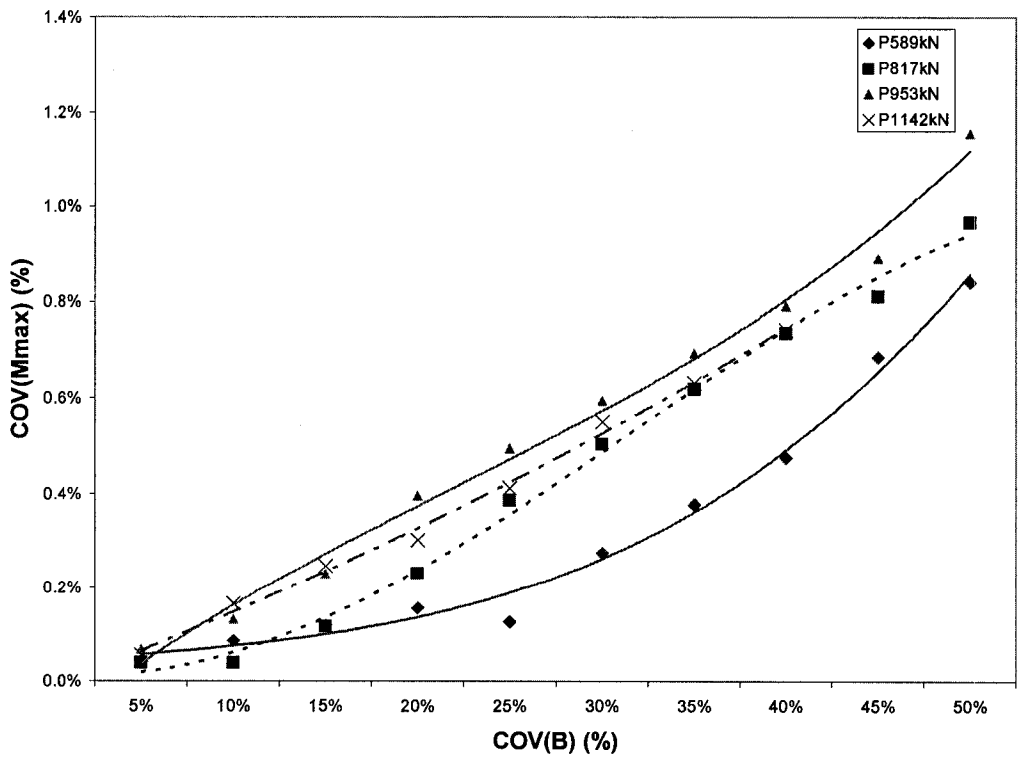

Fig. G.2(a) COV(M_{Max}) for varying COV(B) for pile C in hinged head long pile group with spacing (3D).

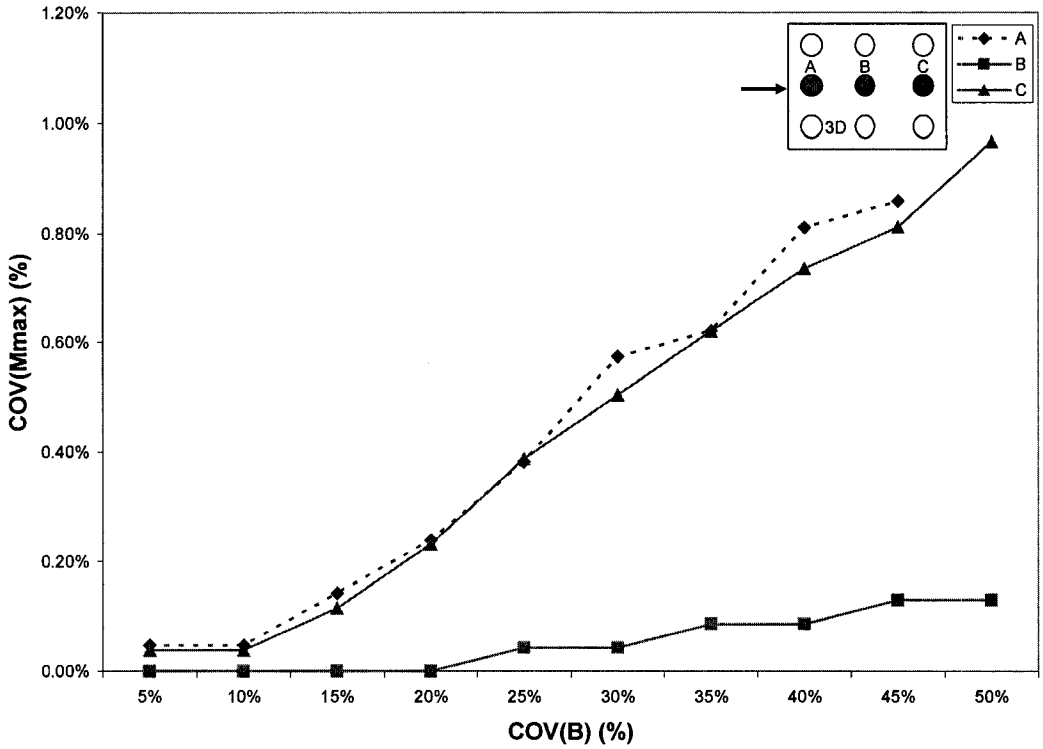

Fig. G.2(b) COV(M_{Max}) for varying COV(B) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (3D) at the optimum lateral load 817 kN.

G.1.2 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (3D) and with 'C' as varying random design variable

Table G.5. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 589 kN and 817 kN.

			P=589 kN (59, 65, 72 kN)				**P=817 kN** (82, 90, 100 kN)			
			Ytop (m)	**Mmax (kN-m)**			**Ytop (m)**	**Mmax (kN-m)**		
COV(C) (%)	**Var (C) $(kPa)^2$**	**Ccurrent (kPa)**	**A/B/C**	**A**	**B**	**C**	**A/B/C**	**A**	**B**	**C**
50.00%	1406.25	37.5	0.0054	80.43	85.37	94.16	0.00933	124	132.3	142.5
45.00%	1139.0625	41.25	0.00492	77.28	82.81	94.06	0.0084	118.9	126.2	136.1
40.00%	900	45	0.00454	74.88	82.9	93.77	0.00769	114.3	121.2	130.7
35.00%	689.0625	48.75	0.00424	75.07	82.88	93.61	0.00708	110	116.8	130.6
30.00%	506.25	52.5	0.00399	75.18	82.9	93.49	0.00656	106.4	114.8	130.6
25.00%	351.5625	56.25	0.00377	75.28	82.92	93.37	0.00612	103.7	114.9	130.4
20.00%	225	60	0.00358	75.37	82.93	93.26	0.00575	103.8	114.9	130.2
15.00%	126.5625	63.75	0.00341	75.46	82.95	93.16	0.00543	104	115	130
10.00%	56.25	67.5	0.00327	75.57	82.98	93.02	0.00516	104.2	115.1	129.6
5.00%	14.0625	71.25	0.00314	75.71	83.06	92.8	0.00494	104.5	115	129.4
0.00%	0	75	0.00302	75.88	83	92.7	0.00474	104.7	115.1	129.2
5.00%	14.0625	78.75	0.00293	75.96	82.94	92.68	0.00457	104.8	115.1	129.1
10.00%	56.25	82.5	0.00283	75.94	82.92	92.73	0.00441	105	115.2	128.8
15.00%	126.5625	86.25	0.00274	75.88	82.92	92.78	0.00427	105.1	115.2	128.6
20.00%	225	90	0.00266	75.84	82.92	92.82	0.00414	105.3	115.1	128.6
25.00%	351.5625	93.75	0.00258	75.84	82.94	92.81	0.00403	105.4	115	128.6
30.00%	506.25	97.5	0.00251	75.83	82.93	92.82	0.00392	105.3	115	128.6
35.00%	689.0625	101.25	0.00245	75.82	82.94	92.83	0.00382	105.3	115	128.7
40.00%	900	105	0.00238	75.82	82.94	92.83	0.00372	105.2	115	128.7
45.00%	1139.0625	108.75	0.00232	75.82	82.94	92.83	0.00363	105.2	115	128.7
50.00%	1406.25	112.5	0.00227	75.83	82.95	92.82	0.00354	105.2	115	128.7

Table G.6. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 953 kN and 1142 kN.

			P=953 kN(95, 100, 120 kN)				P=1142 kN(110,130,140 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	0.0123	152.4	164.1	178	0.0185	196.8	214.6	237.4
45.00%	1139.0625	41.25	0.0111	147.1	157.1	169.2	0.0159	188.5	203.9	223.2
40.00%	900	45	0.01	141.3	150	161.7	0.0141	182	195.6	211.7
35.00%	689.0625	48.75	0.00921	135.8	144.1	155.4	0.0128	175.7	187.1	201.6
30.00%	506.25	52.5	0.0085	130.9	139	152.5	0.0118	169.4	179.8	193.9
25.00%	351.5625	56.25	0.00792	126.8	134.5	152.4	0.0109	163.3	173.3	186.8
20.00%	225	60	0.00741	123	134	152.2	0.0101	157.8	167.5	182.8
15.00%	126.5625	63.75	0.00696	120.9	134	152.1	0.00946	153	162.2	182.7
10.00%	56.25	67.5	0.00657	121.1	134	151.9	0.00889	148.7	160.5	182.5
5.00%	14.0625	71.25	0.00624	121.2	134.1	151.7	0.0084	144.8	160.6	182.3
0.00%	0	75	0.00595	121.4	134.1	151.5	0.00797	145	160.6	182.1
5.00%	14.0625	78.75	0.00569	121.6	134.2	151.3	0.00758	145.2	160.6	181.9
10.00%	56.25	82.5	0.00547	121.9	134.3	150.9	0.00726	145.3	160.6	181.8
15.00%	126.5625	86.25	0.00528	122.2	134.3	150.5	0.00696	145.5	160.7	181.6
20.00%	225	90	0.00512	122.4	134.4	150.2	0.00669	145.6	160.7	181.4
25.00%	351.5625	93.75	0.00496	122.6	134.4	150	0.00644	145.8	160.8	181.2
30.00%	506.25	97.5	0.00482	122.9	134.2	150	0.00623	146.1	160.9	180.7
35.00%	689.0625	101.25	0.00469	122.9	134.2	150	0.00603	146.4	161.1	180.3
40.00%	900	105	0.00459	122.9	134.2	150	0.00586	146.8	161	180
45.00%	1139.0625	108.75	0.00447	122.8	134.2	150.1	0.00572	147	160.9	179.8
50.00%	1406.25	112.5	0.00437	122.7	134.2	150.2	0.00557	147.2	160.8	179.8

Table G.7(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 589 kN and 817 kN.

		P=589 kN		P=817 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	1.10E-08	3.477%	3.42E-08	3.903%
10.00%	5.63E+01	4.84E-08	7.285%	1.41E-07	7.911%
15.00%	1.27E+02	1.12E-07	11.093%	3.36E-07	12.236%
20.00%	2.25E+02	2.12E-07	15.232%	6.48E-07	16.983%
25.00%	3.52E+02	3.54E-07	19.702%	1.09E-06	22.046%
30.00%	5.06E+02	5.48E-07	24.503%	1.74E-06	27.848%
35.00%	6.89E+02	8.01E-07	29.636%	2.66E-06	34.388%
40.00%	9.00E+02	1.17E-06	35.762%	3.94E-06	41.878%
45.00%	1.14E+03	1.69E-06	43.046%	5.69E-06	50.316%
50.00%	1.41E+03	2.45E-06	51.821%	8.38E-06	61.076%

Table G.7(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (3D) and with varying 'C' and lateral load 953 kN and 1142 kN.

		P=953 kN		P=1142 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	7.56E-08	4.622%	1.68E-07	5.144%
10.00%	5.63E+01	3.03E-07	9.244%	6.64E-07	10.226%
15.00%	1.27E+02	7.06E-07	14.118%	1.56E-06	15.684%
20.00%	2.25E+02	1.31E-06	19.244%	2.91E-06	21.393%
25.00%	3.52E+02	2.19E-06	24.874%	4.97E-06	27.980%
30.00%	5.06E+02	3.39E-06	30.924%	7.76E-06	34.944%
35.00%	6.89E+02	5.11E-06	37.983%	1.15E-05	42.472%
40.00%	9.00E+02	7.32E-06	45.462%	1.70E-05	51.694%
45.00%	1.14E+03	1.10E-05	55.714%	2.59E-05	63.864%
50.00%	1.41E+03	1.57E-05	66.639%	4.18E-05	81.117%

Table G.8(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 589 kN.

		P=589 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.015625	0.0036	0.0036	0.16%	0.07%	0.06%
10.00%	56.25	0.034225	0.0009	0.021025	0.24%	0.04%	0.16%
15.00%	126.5625	0.0441	0.000225	0.0361	0.28%	0.02%	0.20%
20.00%	225	0.055225	2.5E-05	0.0484	0.31%	0.01%	0.24%
25.00%	351.5625	0.0784	1E-04	0.03136	0.37%	0.01%	0.19%
30.00%	506.25	0.105625	0.000225	0.112225	0.43%	0.02%	0.36%
35.00%	689.0625	0.140625	0.0009	0.1521	0.49%	0.04%	0.42%
40.00%	900	0.2209	0.0004	0.2209	0.62%	0.02%	0.51%
45.00%	1139.0625	0.5329	0.004225	0.378225	0.96%	0.08%	0.66%
50.00%	1406.25	5.29	1.4641	0.4489	3.03%	1.46%	0.72%

Table G.8(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 817 kN.

		P=817 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.0225	0.0025	0.0225	0.14%	0.04%	0.12%
10.00%	56.25	0.16	0.0025	0.16	0.38%	0.04%	0.31%
15.00%	126.5625	0.3025	0.01	0.49	0.53%	0.09%	0.54%
20.00%	225	0.5625	0.01	0.64	0.72%	0.09%	0.62%
25.00%	351.5625	0.7225	0.0025	0.81	0.81%	0.04%	0.70%
30.00%	506.25	0.3025	0.01	1	0.53%	0.09%	0.77%
35.00%	689.0625	5.5225	0.81	0.9025	2.24%	0.78%	0.74%
40.00%	900	20.7025	9.61	1	4.35%	2.69%	0.77%
45.00%	1139.0625	46.9225	31.36	13.69	6.54%	4.87%	2.86%
50.00%	1406.25	88.36	74.8225	47.61	8.98%	7.52%	5.34%

Table G.8(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 953 kN.

		P=953 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.04	0.0025	0.04	0.16%	0.04%	0.13%
10.00%	56.25	0.16	0.0225	0.25	0.33%	0.11%	0.33%
15.00%	126.5625	0.4225	0.0225	0.64	0.54%	0.11%	0.53%
20.00%	225	0.09	0.04	1	0.25%	0.15%	0.66%
25.00%	351.5625	4.41	0.0025	1.44	1.73%	0.04%	0.79%
30.00%	506.25	16	5.76	1.5625	3.29%	1.79%	0.83%
35.00%	689.0625	41.6025	24.5025	7.29	5.31%	3.69%	1.78%
40.00%	900	84.64	62.41	34.2225	7.58%	5.89%	3.86%
45.00%	1139.0625	147.6225	131.1025	91.2025	10.01%	8.54%	6.30%
50.00%	1406.25	220.5225	223.5025	193.21	12.23%	11.15%	9.17%

Table G.8(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 1142 kN.

		P=1142 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.04	0	0.04	0.14%	0.00%	0.11%
10.00%	56.25	2.89	0.0025	0.1225	1.17%	0.03%	0.19%
15.00%	126.5625	14.0625	0.5625	0.3025	2.59%	0.47%	0.30%
20.00%	225	37.21	11.56	0.49	4.21%	2.12%	0.38%
25.00%	351.5625	76.5625	39.0625	7.84	6.03%	3.89%	1.54%
30.00%	506.25	135.7225	89.3025	43.56	8.03%	5.88%	3.62%
35.00%	689.0625	214.6225	169	113.4225	10.10%	8.09%	5.85%
40.00%	900	309.76	299.29	251.2225	12.14%	10.77%	8.70%
45.00%	1139.0625	430.5625	462.25	470.89	14.31%	13.39%	11.92%
50.00%	1406.25	615.04	723.61	829.44	17.10%	16.75%	15.82%

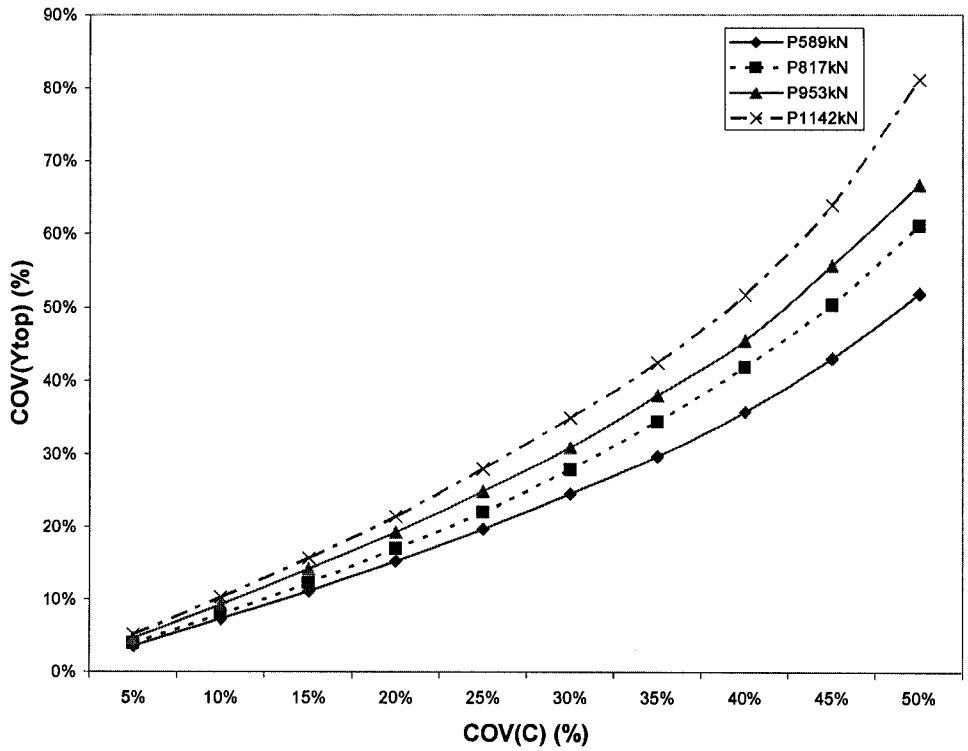

Fig. G.3 COV(Y_{Top}) for varying COV(C) in free head long (10T) pile group with spacing (3D).

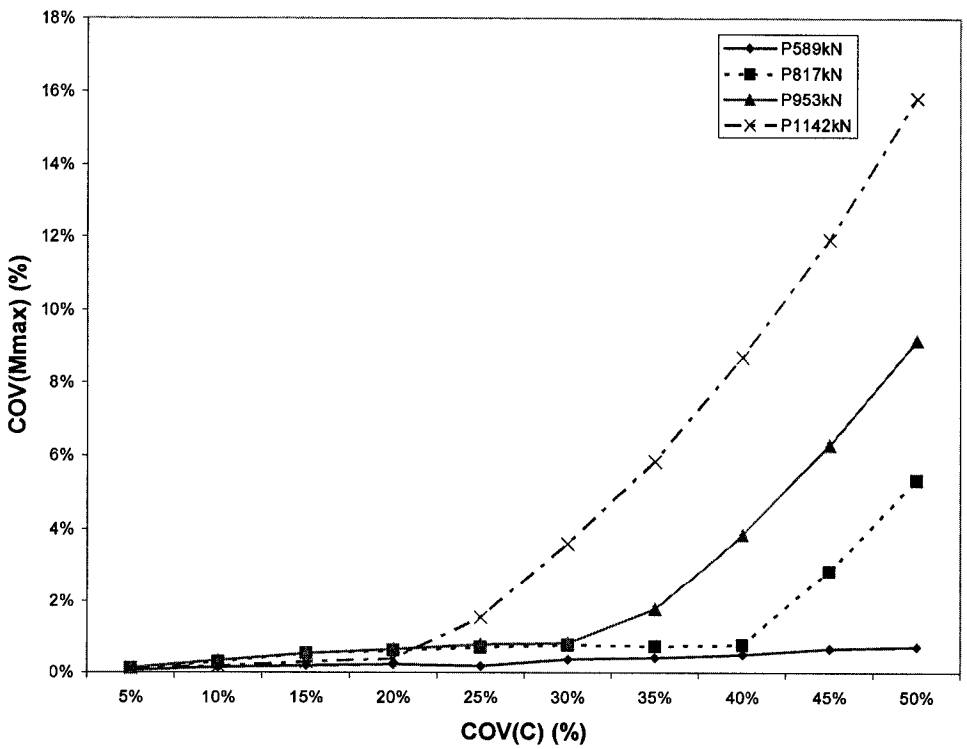

Fig. G.4(a) COV(M_{Max}) for varying COV(C) for pile C in free head long pile group with spacing (3D).

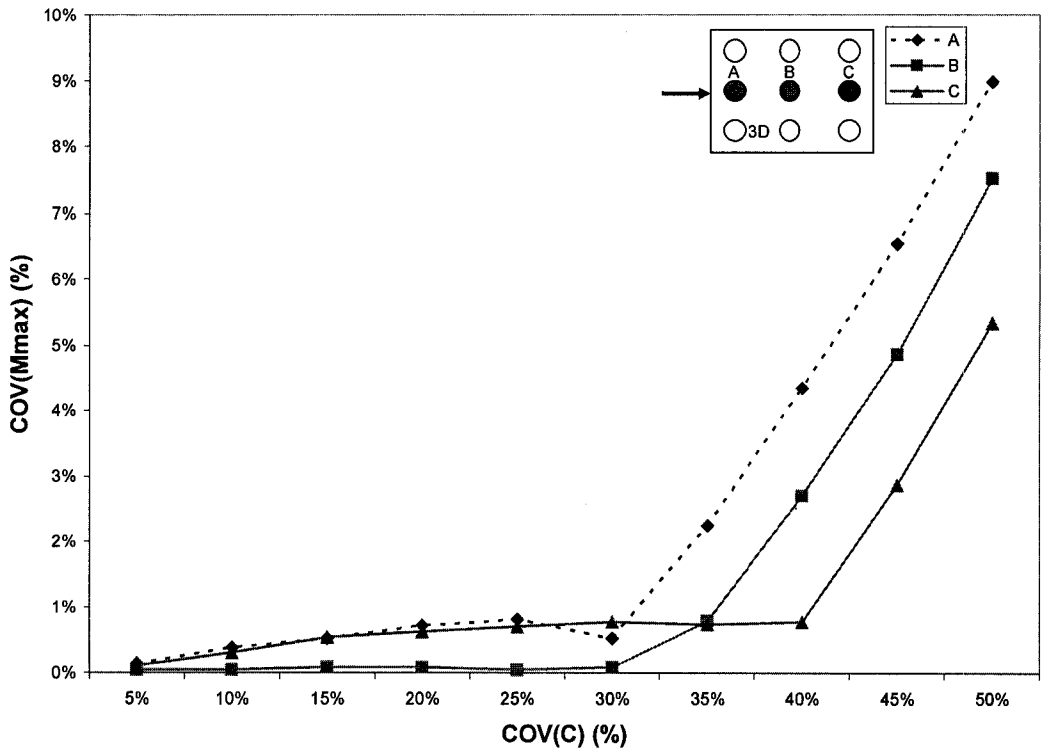

Fig. G.4(b) COV(M_{Max}) for varying COV(C) for pile rows A, B, and C in free head long (10T) pile group with spacing (3D) at the optimum lateral load 817 kN.

G.1.3 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (3D) and with 'ε_{50}' as varying random design variable

Table G.9. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 589 kN and 817 kN.

			P=589 kN (59, 65, 72 kN)				**P=817 kN** (82, 90, 100 kN)			
			Ytop (m)	**Mmax (kN-m)**			**Ytop (m)**	**Mmax (kN-m)**		
COV(ε_{50}) (%)	**Var (ε_{50})**	**ε_{50} current**	**A/B/C**	**A**	**B**	**C**	**A/B/C**	**A**	**B**	**C**
50%	0.00001225	0.0035	0.00235	75.81	82.94	92.84	0.00373	104.7	115	129.3
45%	9.9225E-06	0.00385	0.00244	75.81	82.93	92.84	0.00384	104.8	115	129.2
40%	0.00000784	0.0042	0.00251	75.82	82.93	92.83	0.00395	105	115	129
35%	6.0025E-06	0.00455	0.0026	75.84	82.94	92.81	0.00406	105.1	115	128.9
30%	0.00000441	0.0049	0.00267	75.85	82.92	92.81	0.00415	105.1	115.1	128.8
25%	3.0625E-06	0.00525	0.00273	75.88	82.92	92.78	0.00425	105	115.3	128.7
20%	0.00000196	0.0056	0.0028	75.92	82.92	92.74	0.00435	105	115.3	128.7
15%	1.1025E-06	0.00595	0.00286	75.96	82.92	92.71	0.00445	104.9	115.2	128.8
10%	0.00000049	0.0063	0.00292	75.96	82.94	92.69	0.00456	104.8	115.1	129.1
5%	1.225E-07	0.00665	0.00297	75.96	82.95	92.67	0.00465	104.7	115.1	129.2
0%	0	0.007	0.00302	75.88	83	92.7	0.00474	104.7	115.1	129.2
5%	1.225E-07	0.00735	0.00309	75.74	83.06	92.78	0.00484	104.6	115.1	129.3
10%	0.00000049	0.0077	0.00313	75.72	83.07	92.79	0.00494	104.5	115.1	129.4
15%	1.1025E-06	0.00805	0.00318	75.67	83.04	92.87	0.00502	104.5	115	129.4
20%	0.00000196	0.0084	0.00323	75.61	83.01	92.96	0.00511	104.4	115	129.5
25%	3.0625E-06	0.00875	0.00328	75.55	82.97	93.05	0.00519	104.4	115	129.5
30%	0.00000441	0.0091	0.00334	75.51	82.95	93.11	0.00527	104.4	115	129.6
35%	6.0025E-06	0.00945	0.00338	75.48	82.95	93.14	0.00536	104.3	115	129.6
40%	0.00000784	0.0098	0.00343	75.45	82.94	93.17	0.00544	104.3	115	129.6
45%	9.9225E-06	0.01015	0.00348	75.43	82.94	93.2	0.00552	104.3	115	129.7
50%	0.00001225	0.0105	0.00353	75.4	82.94	93.23	0.0056	104.2	115	129.7

Table G.10. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 953 kN and 1142 kN.

			P=953 kN(95, 100, 120 kN)				P=1142 kN(110,130,140 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00475	122.2	134	150.8	0.00641	145.7	161	181.1
45%	9.9225E-06	0.00385	0.00487	122.3	134.1	150.6	0.00657	145.5	160.8	181.4
40%	0.00000784	0.0042	0.005	122.1	134.3	150.6	0.00674	145.3	160.7	181.7
35%	6.0025E-06	0.00455	0.00512	121.9	134.4	150.7	0.0069	145.3	160.7	181.8
30%	0.00000441	0.0049	0.00525	121.8	134.3	150.9	0.00708	145.2	160.7	181.8
25%	3.0625E-06	0.00525	0.00538	121.6	134.1	151.3	0.00724	145.2	160.7	181.9
20%	0.00000196	0.0056	0.00548	121.6	134.1	151.3	0.00739	145.2	160.6	181.9
15%	1.1025E-06	0.00595	0.00561	121.5	134.1	151.4	0.00754	145.1	160.6	182
10%	0.00000049	0.0063	0.00573	121.5	134.1	151.5	0.00768	145.1	160.6	182
5%	1.225E-07	0.00665	0.00584	121.5	134.1	151.5	0.00782	145	160.6	182.1
0%	0	0.007	0.00595	121.4	134.1	151.5	0.00797	145	160.6	182.1
5%	1.225E-07	0.00735	0.00606	121.4	134.1	151.6	0.00813	144.9	160.6	182.2
10%	0.00000049	0.0077	0.00616	121.4	134.1	151.6	0.00826	144.9	160.6	182.2
15%	1.1025E-06	0.00805	0.00626	121.3	134.1	151.6	0.00839	144.9	160.6	182.3
20%	0.00000196	0.0084	0.00637	121.3	134.1	151.6	0.00852	144.9	160.6	182.3
25%	3.0625E-06	0.00875	0.00647	121.3	134.1	151.6	0.00864	145.5	160.6	182.3
30%	0.00000441	0.0091	0.00659	121.3	134.1	151.7	0.00877	146.3	160.6	182.4
35%	6.0025E-06	0.00945	0.00669	121.3	134.1	151.6	0.00889	147	160.6	182.4
40%	0.00000784	0.0098	0.00678	121.3	134.1	151.6	0.00901	147.8	160.5	182.4
45%	9.9225E-06	0.01015	0.00688	121.3	134.1	151.6	0.00913	148.5	160.5	182.4
50%	0.00001225	0.0105	0.00698	121.3	134.1	151.6	0.00925	149.5	160.5	182.4

Table G.11(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 589 kN and 817 kN.

		P=589 kN		P=817 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	3.60E-09	1.987%	9.02E-09	2.004%
10%	4.90E-07	1.10E-08	3.477%	3.61E-08	4.008%
15%	1.10E-06	2.56E-08	5.298%	8.12E-08	6.013%
20%	1.96E-06	4.62E-08	7.119%	1.44E-07	8.017%
25%	3.06E-06	7.56E-08	9.106%	2.21E-07	9.916%
30%	4.41E-06	1.12E-07	11.093%	3.14E-07	11.814%
35%	6.00E-06	1.52E-07	12.914%	4.23E-07	13.713%
40%	7.84E-06	2.12E-07	15.232%	5.55E-07	15.717%
45%	9.92E-06	2.70E-07	17.219%	7.06E-07	17.722%
50%	1.23E-05	3.48E-07	19.536%	8.74E-07	19.726%

Table G.11(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 953 kN and 1142 kN.

		P=953 kN		P=1142 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	1.21E-08	1.849%	2.40E-08	1.945%
10%	4.90E-07	4.62E-08	3.613%	8.41E-08	3.639%
15%	1.10E-06	1.06E-07	5.462%	1.81E-07	5.332%
20%	1.96E-06	1.98E-07	7.479%	3.19E-07	7.089%
25%	3.06E-06	2.97E-07	9.160%	4.90E-07	8.783%
30%	4.41E-06	4.49E-07	11.261%	7.14E-07	10.602%
35%	6.00E-06	6.16E-07	13.193%	9.90E-07	12.484%
40%	7.84E-06	7.92E-07	14.958%	1.29E-06	14.241%
45%	9.92E-06	1.01E-06	16.891%	1.64E-06	16.060%
50%	1.23E-05	1.24E-06	18.739%	2.02E-06	17.817%

Table G.12(a) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 589 kN.

		P=589 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0121	0.003025	0.003025	0.14%	0.07%	0.06%
10%	4.90E-07	0.0144	0.004225	0.0025	0.16%	0.08%	0.05%
15%	1.10E-06	0.021025	0.0036	0.0064	0.19%	0.07%	0.09%
20%	1.96E-06	0.024025	0.002025	0.0121	0.20%	0.05%	0.12%
25%	3.06E-06	0.027225	0.000625	0.00729	0.22%	0.03%	0.09%
30%	4.41E-06	0.0289	0.000225	0.0225	0.22%	0.02%	0.16%
35%	6.00E-06	0.0324	2.5E-05	0.027225	0.24%	0.01%	0.18%
40%	7.84E-06	0.034225	2.5E-05	0.0289	0.24%	0.01%	0.18%
45%	9.92E-06	0.0361	2.5E-05	0.0324	0.25%	0.01%	0.19%
50%	1.23E-05	0.042025	0	0.038025	0.27%	0.00%	0.21%

Table G.12(b) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 817 kN.

		P=817 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0025	0	0.0025	0.05%	0.00%	0.04%
10%	4.90E-07	0.0225	0	0.0225	0.14%	0.00%	0.12%
15%	1.10E-06	0.04	0.01	0.09	0.19%	0.09%	0.23%
20%	1.96E-06	0.09	0.0225	0.16	0.29%	0.13%	0.31%
25%	3.06E-06	0.09	0.0225	0.16	0.29%	0.13%	0.31%
30%	4.41E-06	0.1225	0.0025	0.16	0.33%	0.04%	0.31%
35%	6.00E-06	0.16	0	0.1225	0.38%	0.00%	0.27%
40%	7.84E-06	0.1225	0	0.09	0.33%	0.00%	0.23%
45%	9.92E-06	0.0625	0	0.0625	0.24%	0.00%	0.19%
50%	1.23E-05	0.0625	0	0.04	0.24%	0.00%	0.15%

Table G.12(c) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 953 kN.

		P=953 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0025	0	0.0025	0.04%	0.00%	0.03%
10%	4.90E-07	0.0025	0	0.0025	0.04%	0.00%	0.03%
15%	1.10E-06	0.01	0	0.01	0.08%	0.00%	0.07%
20%	1.96E-06	0.0225	0	0.0225	0.12%	0.00%	0.10%
25%	3.06E-06	0.0225	0	0.0225	0.12%	0.00%	0.10%
30%	4.41E-06	0.0625	0.01	0.16	0.21%	0.07%	0.26%
35%	6.00E-06	0.09	0.0225	0.2025	0.25%	0.11%	0.30%
40%	7.84E-06	0.16	0.01	0.25	0.33%	0.07%	0.33%
45%	9.92E-06	0.25	0	0.25	0.41%	0.00%	0.33%
50%	1.23E-05	0.2025	0.0025	0.16	0.37%	0.04%	0.26%

Table G.12(d) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 1142 kN.

		P=1142 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0025	0	0.0025	0.03%	0.00%	0.03%
10%	4.90E-07	0.01	0	0.01	0.07%	0.00%	0.05%
15%	1.10E-06	0.01	0	0.0225	0.07%	0.00%	0.08%
20%	1.96E-06	0.0225	0	0.04	0.10%	0.00%	0.11%
25%	3.06E-06	0.0225	0.0025	0.04	0.10%	0.03%	0.11%
30%	4.41E-06	0.3025	0.0025	0.09	0.38%	0.03%	0.16%
35%	6.00E-06	0.7225	0.0025	0.09	0.59%	0.03%	0.16%
40%	7.84E-06	1.5625	0.01	0.1225	0.86%	0.06%	0.19%
45%	9.92E-06	2.25	0.0225	0.25	1.03%	0.09%	0.27%
50%	1.23E-05	3.61	0.0625	0.4225	1.31%	0.16%	0.36%

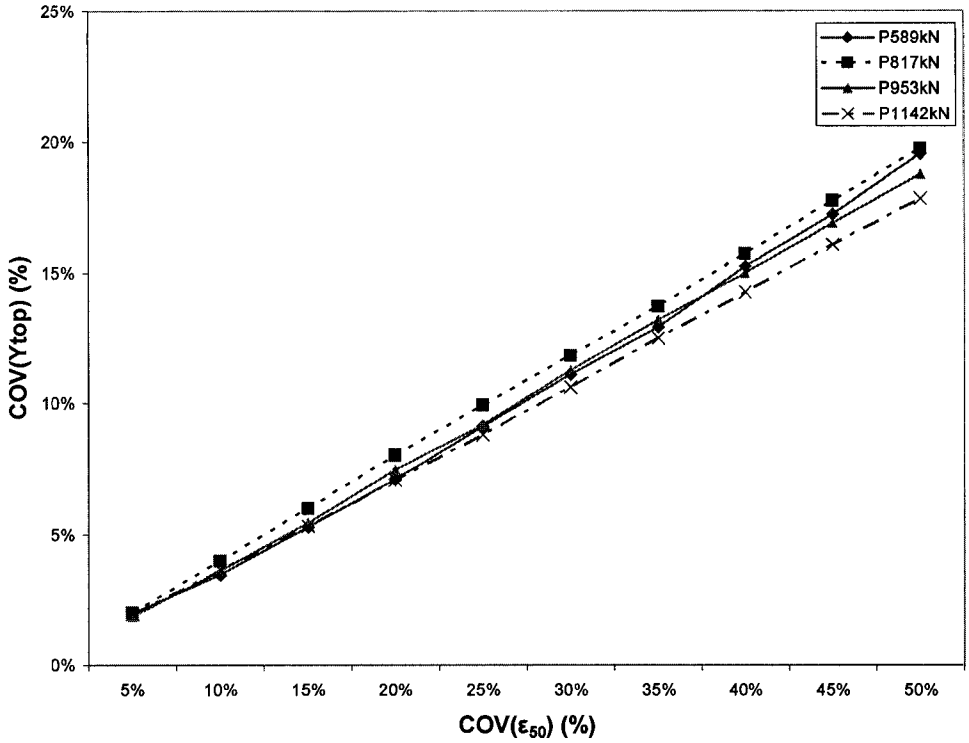

Fig. G.5 COV(Y_{Top}) for varying COV(ε_{50}) in hinged head long (10T) pile group with spacing (3D).

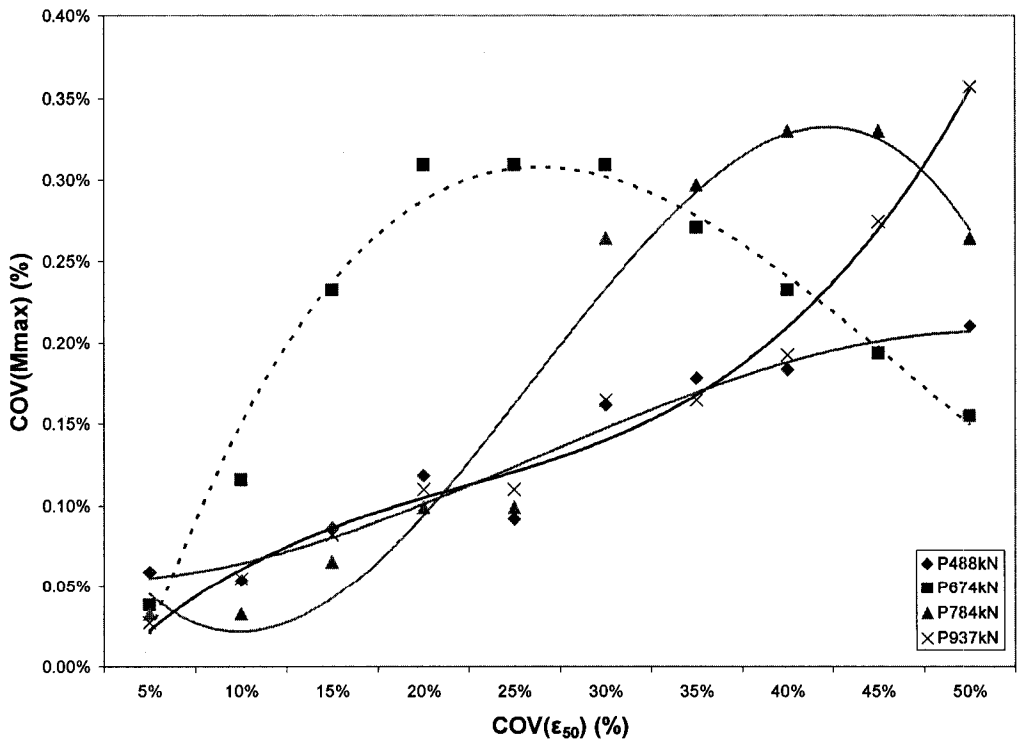

Fig. G.6(a) COV(M_{Max}) for varying COV(ε_{50}) for pile C in hinged head long pile group with spacing (3D).

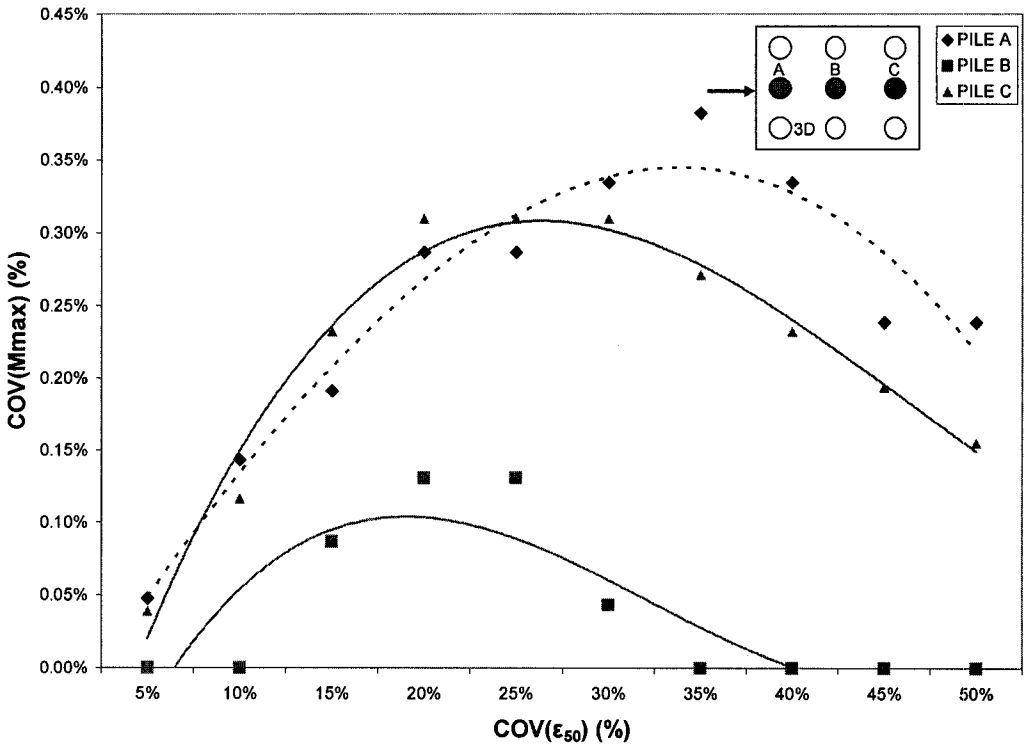

Fig. G.6(b) COV(M_{Max}) for varying COV(ε_{50}) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (3D) at the optimum lateral load 817 kN.

G.1.4 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (3D) and with 'EI' as varying random design variable

Table G.13. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 589 kN and 817 kN.

			P=589 kN (59, 65, 72 kN)				**P=817 kN** (82, 90, 100 kN)			
			Ytop (m)	**Mmax (kN-m)**			**Ytop (m)**	**Mmax (kN-m)**		
COV(EI) (%)	**Var (EI) $(kN.m^2)^2$**	**EIcurrent $(KN.m^2)$**	**A/B/C**	**A**	**B**	**C**	**A/B/C**	**A**	**B**	**C**
50%	2.50E+09	55000	0.00471	76.08	82.96	92.52	0.00741	105.1	115.1	128.7
45%	2.03E+09	60500	0.00444	76.08	82.96	92.53	0.00696	105	115.2	128.7
40%	1.60E+09	66000	0.00421	76.08	82.95	92.53	0.00658	105	115.2	128.8
35%	1.23E+09	71500	0.004	76.08	82.95	92.54	0.00625	105	115.2	128.8
30%	9.00E+08	77000	0.00382	76.08	82.95	92.54	0.00596	105	115.2	128.8
25%	6.25E+08	82500	0.00366	76.07	82.95	92.55	0.00571	104.9	115.3	128.7
20%	4.00E+08	88000	0.00352	76.06	82.96	92.55	0.0055	104.8	115.2	128.9
15%	2.25E+08	93500	0.00339	76.02	82.98	92.57	0.0053	104.8	115.1	129
10%	1.00E+08	99000	0.00326	76.04	82.96	92.57	0.0051	104.9	115.1	129
5%	2.50E+07	104500	0.00316	76	82.98	92.6	0.00494	104.8	115.1	129.1
0%	0.00E+00	110000	0.00306	75.96	83	92.62	0.00479	104.8	115.1	129.1
5%	2.50E+07	115500	0.00297	75.91	83.02	92.64	0.00466	104.7	115.1	129.2
10%	1.00E+08	121000	0.0029	75.81	83.06	92.71	0.00454	104.7	115.1	129.2
15%	2.25E+08	126500	0.00282	75.77	83.08	92.74	0.00442	104.6	115	129.3
20%	4.00E+08	132000	0.00275	75.73	83.07	92.78	0.00431	104.6	115	129.3
25%	6.25E+08	137500	0.00267	75.74	83.09	92.75	0.00421	104.5	115	129.4
30%	9.00E+08	143000	0.00261	75.7	83.09	92.79	0.00412	104.5	115	129.4
35%	1.23E+09	148500	0.00255	75.67	83.08	92.84	0.00403	104.5	115	129.5
40%	1.60E+09	154000	0.0025	75.64	83.07	92.88	0.00394	104.4	115	129.5
45%	2.03E+09	159500	0.00244	75.61	83.06	92.92	0.00386	104.4	115	129.6
50%	2.50E+09	165000	0.0024	75.58	83.04	92.97	0.00379	104.4	115	129.6

Table G.14. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 953 kN and 1142 kN.

			P=953 kN(95, 100, 120 kN)				P=1142 kN(110,130,140 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	2.50E+09	55000	0.00944	122.1	134.3	150.7	0.0128	145.6	160.7	181.4
45%	2.03E+09	60500	0.00885	122	134.2	150.8	0.012	145.6	160.7	181.4
40%	1.60E+09	66000	0.00833	121.9	134.2	150.9	0.0113	145.5	160.7	181.5
35%	1.23E+09	71500	0.0079	121.9	134.2	150.9	0.0107	145.4	160.7	181.6
30%	9.00E+08	77000	0.00753	121.8	134.2	151	0.0101	145.4	160.7	181.7
25%	6.25E+08	82500	0.00721	121.7	134.1	151.2	0.00969	145.3	160.7	181.7
20%	4.00E+08	88000	0.00692	121.7	134.1	151.2	0.00929	145.3	160.7	181.8
15%	2.25E+08	93500	0.00666	121.6	134.1	151.3	0.00893	145.2	160.7	181.8
10%	1.00E+08	99000	0.00642	121.6	134.1	151.3	0.0086	145.2	160.7	181.9
5%	2.50E+07	104500	0.00621	121.5	134.1	151.4	0.00831	145.1	160.6	182
0%	0.00E+00	110000	0.00601	121.5	134.1	151.4	0.00804	145.1	160.6	182
5%	2.50E+07	115500	0.00583	121.5	134.2	151.4	0.00779	145.1	160.6	182.1
10%	1.00E+08	121000	0.00566	121.4	134.2	151.5	0.00757	145	160.6	182.1
15%	2.25E+08	126500	0.00551	121.4	134.1	151.5	0.00738	145	160.6	182.2
20%	4.00E+08	132000	0.00537	121.4	134.1	151.5	0.00718	145.1	160.6	182.3
25%	6.25E+08	137500	0.00524	121.4	134.2	151.5	0.007	146	160.5	182.3
30%	9.00E+08	143000	0.00512	121.4	134.2	151.5	0.00683	146.8	160.5	182.3
35%	1.23E+09	148500	0.00501	121.4	134.2	151.5	0.00667	147.6	160.5	182.4
40%	1.60E+09	154000	0.0049	121.4	134.2	151.5	0.00653	148.4	160.5	182.4
45%	2.03E+09	159500	0.0048	121.4	134.2	151.4	0.00639	149.2	160.5	182.4
50%	2.50E+09	165000	0.00472	121.4	134.2	151.5	0.00626	149.9	160.5	182.4

Table G.15(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 589 kN and 817 kN.

		P=589 kN		P=817 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	2.50E+07	7.46E-09	2.860%	1.62E-08	2.685%
10%	1.00E+08	2.68E-08	5.418%	6.48E-08	5.370%
15%	2.25E+08	6.71E-08	8.579%	1.60E-07	8.439%
20%	4.00E+08	1.23E-07	11.589%	2.93E-07	11.412%
25%	6.25E+08	2.03E-07	14.901%	4.65E-07	14.384%
30%	9.00E+08	3.03E-07	18.212%	7.00E-07	17.645%
35%	1.23E+09	4.34E-07	21.824%	1.02E-06	21.289%
40%	1.60E+09	6.04E-07	25.738%	1.44E-06	25.316%
45%	2.03E+09	8.26E-07	30.102%	1.99E-06	29.728%
50%	2.50E+09	1.10E-06	34.768%	2.71E-06	34.714%

Table G.15(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 953 kN and 1142 kN.

		P=953 kN		P=1142 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	2.50E+07	2.98E-08	2.903%	5.59E-08	2.966%
10%	1.00E+08	1.19E-07	5.806%	2.19E-07	5.874%
15%	2.25E+08	2.73E-07	8.785%	4.96E-07	8.840%
20%	4.00E+08	4.96E-07	11.841%	9.20E-07	12.034%
25%	6.25E+08	8.02E-07	15.050%	1.50E-06	15.342%
30%	9.00E+08	1.20E-06	18.411%	2.21E-06	18.649%
35%	1.23E+09	1.73E-06	22.078%	3.36E-06	22.984%
40%	1.60E+09	2.43E-06	26.203%	4.70E-06	27.204%
45%	2.03E+09	3.39E-06	30.940%	6.50E-06	31.995%
50%	2.50E+09	4.60E-06	36.058%	8.84E-06	37.299%

Table G.16(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 589 kN.

		P=589 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0.0016736	0.0003306	0.0003306	0.05%	0.02%	0.02%
10%	1.00E+08	0.0109298	0.0020661	0.0040496	0.14%	0.05%	0.07%
15%	2.25E+08	0.0129132	0.0020661	0.0059711	0.15%	0.05%	0.08%
20%	4.00E+08	0.0225	0.0025	0.0109298	0.20%	0.06%	0.11%
25%	6.25E+08	0.0225	0.0040496	0.0033058	0.20%	0.08%	0.06%
30%	9.00E+08	0.0298347	0.0040496	0.0129132	0.23%	0.08%	0.12%
35%	1.23E+09	0.0347314	0.0034917	0.018595	0.25%	0.07%	0.15%
40%	1.60E+09	0.04	0.0029752	0.0253099	0.26%	0.07%	0.17%
45%	2.03E+09	0.0456405	0.0020661	0.0314256	0.28%	0.05%	0.19%
50%	2.50E+09	0.0516529	0.0013223	0.0418388	0.30%	0.04%	0.22%

Table G.16(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 817 kN.

		P=817 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0.0020661	0	0.0020661	0.04%	0.00%	0.04%
10%	1.00E+08	0.0082645	0	0.0082645	0.09%	0.00%	0.07%
15%	2.25E+08	0.0082645	0.0020661	0.018595	0.09%	0.04%	0.11%
20%	4.00E+08	0.0082645	0.0082645	0.0330579	0.09%	0.08%	0.14%
25%	6.25E+08	0.0330579	0.018595	0.1012397	0.17%	0.12%	0.25%
30%	9.00E+08	0.0516529	0.0082645	0.0743802	0.22%	0.08%	0.21%
35%	1.23E+09	0.0516529	0.0082645	0.1012397	0.22%	0.08%	0.25%
40%	1.60E+09	0.0743802	0.0082645	0.1012397	0.26%	0.08%	0.25%
45%	2.03E+09	0.0743802	0.0082645	0.1673554	0.26%	0.08%	0.32%
50%	2.50E+09	0.1012397	0.0020661	0.1673554	0.30%	0.04%	0.32%

Table G.16(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 953 kN.

		P=953 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0	0.0020661	0	0.00%	0.03%	0.00%
10%	1.00E+08	0.0082645	0.0020661	0.0082645	0.07%	0.03%	0.06%
15%	2.25E+08	0.0082645	0	0.0082645	0.07%	0.00%	0.06%
20%	4.00E+08	0.018595	0	0.018595	0.11%	0.00%	0.09%
25%	6.25E+08	0.018595	0.0020661	0.018595	0.11%	0.03%	0.09%
30%	9.00E+08	0.0330579	0	0.0516529	0.15%	0.00%	0.15%
35%	1.23E+09	0.0516529	0	0.0743802	0.19%	0.00%	0.18%
40%	1.60E+09	0.0516529	0	0.0743802	0.19%	0.00%	0.18%
45%	2.03E+09	0.0743802	0	0.0743802	0.22%	0.00%	0.18%
50%	2.50E+09	0.1012397	0.0020661	0.1322314	0.26%	0.03%	0.24%

Table G.16(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 1142 kN.

		P=1142 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0	0	0.0020661	0.00%	0.00%	0.02%
10%	1.00E+08	0.0082645	0.0020661	0.0082645	0.06%	0.03%	0.05%
15%	2.25E+08	0.0082645	0.0020661	0.0330579	0.06%	0.03%	0.10%
20%	4.00E+08	0.0082645	0.0020661	0.0516529	0.06%	0.03%	0.12%
25%	6.25E+08	0.1012397	0.0082645	0.0743802	0.22%	0.06%	0.15%
30%	9.00E+08	0.4049587	0.0082645	0.0743802	0.44%	0.06%	0.15%
35%	1.23E+09	1	0.0082645	0.1322314	0.69%	0.06%	0.20%
40%	1.60E+09	1.7376033	0.0082645	0.1673554	0.91%	0.06%	0.22%
45%	2.03E+09	2.677686	0.0082645	0.2066116	1.13%	0.06%	0.25%
50%	2.50E+09	3.8202479	0.0082645	0.2066116	1.35%	0.06%	0.25%

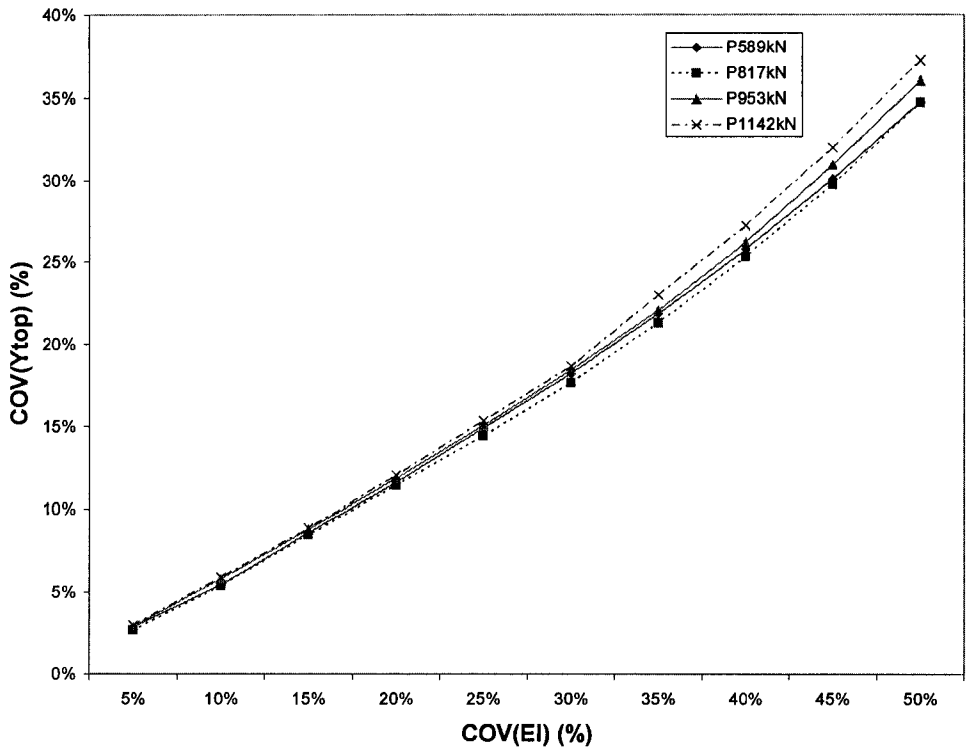

Fig. G.7 COV(Y_{Top}) for varying COV(EI) in hinged head long (10T) pile group with spacing (3D).

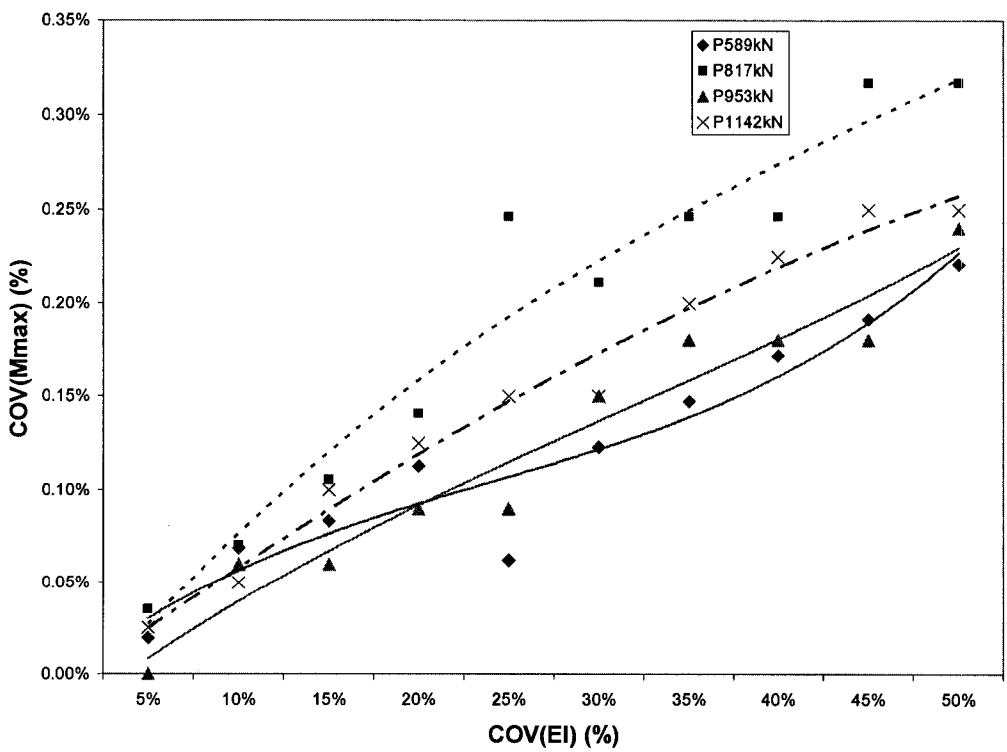

Fig. G.8(a) COV(M_{Max}) for varying COV(EI) for pile C in hinged head long pile group with spacing (3D).

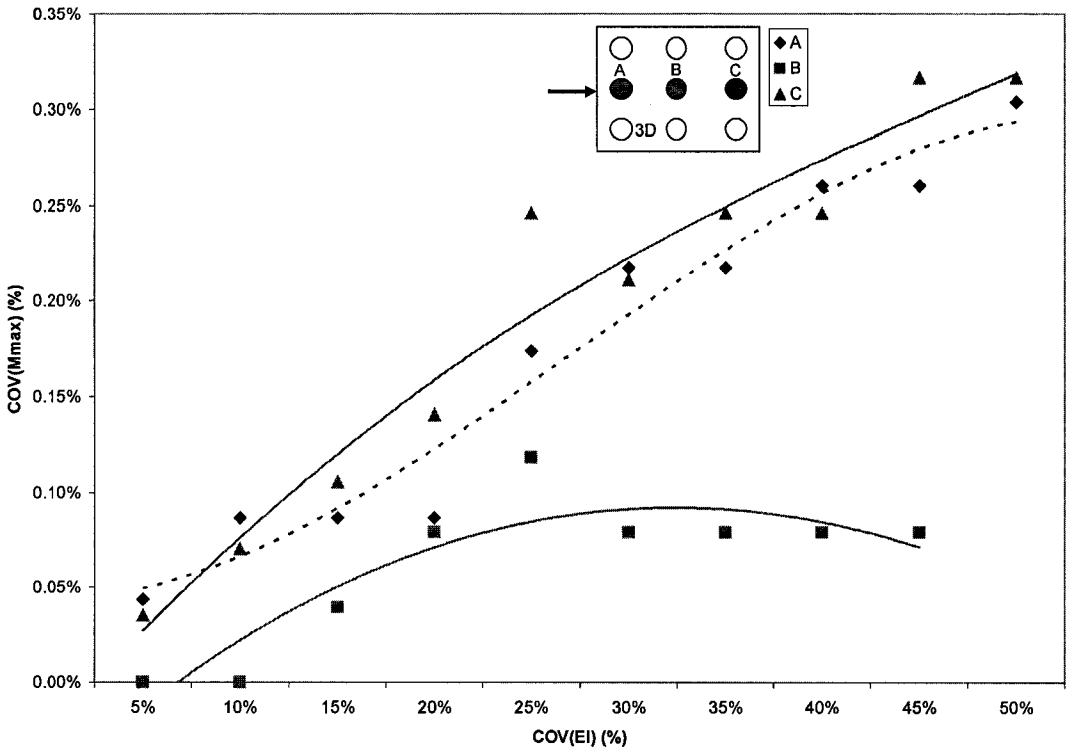

Fig. G.8(b) COV(M_{Max}) for varying COV(EI) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (3D) at the optimum lateral load 817 kN.

G.1.5 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (3D) and with 'k' as varying random design variable

Table G.17. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 589 kN and 817 kN.

			P=589 kN (59, 65, 72 kN)				P=817 kN (82, 90, 100 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00312	75.92	83.32	92.33	0.00483	105	115	129
45%	3.75E+09	74800	0.00309	75.6	82.9	93.07	0.00481	105.1	115	128.9
40%	2.96E+09	81600	0.00308	75.67	82.91	93.01	0.00478	105.1	115.1	128.8
35%	2.27E+09	88400	0.00307	75.72	82.91	92.94	0.00477	104.9	115.2	128.8
30%	1.66E+09	95200	0.00306	75.78	82.92	92.88	0.00476	104.8	115.2	128.9
25%	1.16E+09	102000	0.00305	75.83	82.91	92.83	0.00476	104.8	115.1	129
20%	7.40E+08	108800	0.00304	75.89	82.91	92.77	0.00475	104.7	115.1	129.1
15%	4.16E+08	115600	0.00304	75.92	82.93	92.73	0.00474	104.7	115.1	129.2
10%	1.85E+08	122400	0.00304	75.9	82.96	92.71	0.00474	104.7	115.1	129.2
5%	4.62E+07	129200	0.00302	75.92	82.96	92.7	0.00474	104.7	115.1	129.2
0%	0.00E+00	136000	0.00302	75.88	83	92.7	0.00474	104.7	115.1	129.2
5%	4.62E+07	142800	0.00302	75.84	83.04	92.7	0.00474	104.7	115.1	129.2
10%	1.85E+08	149600	0.00302	75.81	83.06	92.71	0.00474	104.7	115.1	129.2
15%	4.16E+08	156400	0.00302	75.79	83.07	92.72	0.00474	104.7	115.1	129.2
20%	7.40E+08	163200	0.00302	75.78	83.05	92.75	0.00474	104.7	115.1	129.2
25%	1.16E+09	170000	0.00302	75.76	83.04	92.77	0.00474	104.7	115.1	129.2
30%	1.66E+09	176800	0.00302	75.76	83.03	92.79	0.00474	104.7	115.1	129.2
35%	2.27E+09	183600	0.00302	75.75	83.02	92.81	0.00474	104.7	115.1	129.2
40%	2.96E+09	190400	0.00301	75.74	83.01	92.83	0.00474	104.7	115.1	129.2
45%	3.75E+09	197200	0.00301	75.73	83	92.85	0.00474	104.7	115.1	129.2
50%	4.62E+09	204000	0.00301	75.72	82.99	92.87	0.00474	104.7	115.1	129.2

Table G.18. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 953 kN and 1142 kN.

			P=953 kN(95, 100, 120 kN)				P=1142 kN(110,130,140 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00601	121.9	134.2	150.9	0.00797	145	160.6	182.1
45%	3.75E+09	74800	0.00597	121.7	134.4	150.9	0.00797	145	160.6	182.1
40%	2.96E+09	81600	0.00596	121.6	134.3	151.2	0.00797	145	160.6	182.1
35%	2.27E+09	88400	0.00595	121.5	134.1	151.4	0.00797	145	160.6	182.1
30%	1.66E+09	95200	0.00595	121.4	134.1	151.5	0.00797	145	160.6	182.1
25%	1.16E+09	102000	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
20%	7.40E+08	108800	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
15%	4.16E+08	115600	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
10%	1.85E+08	122400	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
5%	4.62E+07	129200	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
0%	0.00E+00	136000	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
5%	4.62E+07	142800	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
10%	1.85E+08	149600	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
15%	4.16E+08	156400	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
20%	7.40E+08	163200	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
25%	1.16E+09	170000	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
30%	1.66E+09	176800	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
35%	2.27E+09	183600	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
40%	2.96E+09	190400	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
45%	3.75E+09	197200	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
50%	4.62E+09	204000	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1

Table G.19(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 589 kN and 817 kN.

		P=589 kN		P=817 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	1.00E-10	0.331%	0.00E+00	0.000%
15%	4.16E+08	1.00E-10	0.331%	0.00E+00	0.000%
20%	7.40E+08	1.00E-10	0.331%	2.50E-11	0.105%
25%	1.16E+09	2.25E-10	0.497%	1.00E-10	0.211%
30%	1.66E+09	4.00E-10	0.662%	1.00E-10	0.211%
35%	2.27E+09	6.25E-10	0.828%	2.25E-10	0.316%
40%	2.96E+09	1.22E-09	1.159%	4.00E-10	0.422%
45%	3.75E+09	1.60E-09	1.325%	1.22E-09	0.738%
50%	4.62E+09	3.02E-09	1.821%	2.02E-09	0.949%

Table G.19(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (3D) and with varying 'k' and lateral load 953 kN and 1142 kN.

		P=953 kN		P=1142 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	0.00E+00	0.000%
20%	7.40E+08	0.00E+00	0.000%	0.00E+00	0.000%
25%	1.16E+09	0.00E+00	0.000%	0.00E+00	0.000%
30%	1.66E+09	0.00E+00	0.000%	2.50E-11	0.063%
35%	2.27E+09	0.00E+00	0.000%	2.50E-11	0.063%
40%	2.96E+09	2.50E-11	0.084%	2.50E-11	0.063%
45%	3.75E+09	1.00E-10	0.168%	2.50E-11	0.063%
50%	4.62E+09	9.00E-10	0.504%	2.50E-11	0.063%

Table G.20(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 589 kN.

		P=589 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.0016	0.0016	0	0.05%	0.05%	0.00%
10%	1.85E+08	0.002025	0.0025	0	0.06%	0.06%	0.00%
15%	4.16E+08	0.004225	0.0049	2.5E-05	0.09%	0.08%	0.01%
20%	7.40E+08	0.003025	0.0049	1E-04	0.07%	0.08%	0.01%
25%	1.16E+09	0.001225	0.004225	0.00036	0.05%	0.08%	0.02%
30%	1.66E+09	1E-04	0.003025	0.002025	0.01%	0.07%	0.05%
35%	2.27E+09	0.000225	0.003025	0.004225	0.02%	0.07%	0.07%
40%	2.96E+09	0.001225	0.0025	0.0081	0.05%	0.06%	0.10%
45%	3.75E+09	0.004225	0.0025	0.0121	0.09%	0.06%	0.12%
50%	4.62E+09	0.01	0.027225	0.0729	0.13%	0.20%	0.29%

Table G.20(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 817 kN.

		P=817 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0	0	0.00%	0.00%	0.00%
10%	1.85E+08	0	0	0	0.00%	0.00%	0.00%
15%	4.16E+08	0	0	0	0.00%	0.00%	0.00%
20%	7.40E+08	0	0	0.0025	0.00%	0.00%	0.04%
25%	1.16E+09	0.0025	0	0.01	0.05%	0.00%	0.08%
30%	1.66E+09	0.0025	0.0025	0.0225	0.05%	0.04%	0.12%
35%	2.27E+09	0.01	0.0025	0.04	0.10%	0.04%	0.15%
40%	2.96E+09	0.04	0	0.04	0.19%	0.00%	0.15%
45%	3.75E+09	0.04	0.0025	0.0225	0.19%	0.04%	0.12%
50%	4.62E+09	0.0225	0.0025	0.01	0.14%	0.04%	0.08%

Table G.20(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 953 kN.

		P=953 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0	0	0.00%	0.00%	0.00%
10%	1.85E+08	0	0	0	0.00%	0.00%	0.00%
15%	4.16E+08	0	0	0	0.00%	0.00%	0.00%
20%	7.40E+08	0	0	0	0.00%	0.00%	0.00%
25%	1.16E+09	0	0	0	0.00%	0.00%	0.00%
30%	1.66E+09	0	0	0	0.00%	0.00%	0.00%
35%	2.27E+09	0.0025	0	0.0025	0.04%	0.00%	0.03%
40%	2.96E+09	0.01	0.01	0.0225	0.08%	0.07%	0.10%
45%	3.75E+09	0.0225	0.0225	0.09	0.12%	0.11%	0.20%
50%	4.62E+09	0.0625	0.0025	0.09	0.21%	0.04%	0.20%

Table G.20(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 1142 kN.

		P=1142 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	1.85E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	4.16E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	7.40E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	1.16E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	1.66E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	2.27E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	2.96E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	3.75E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
50%	4.62E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%

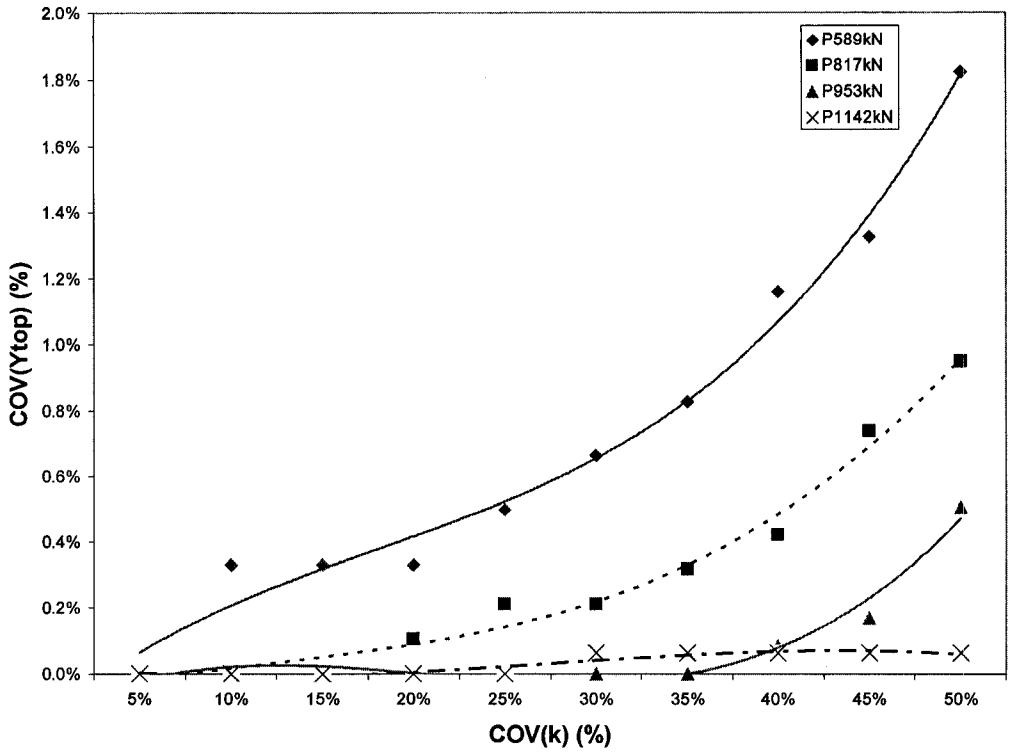

Fig. G.9 COV(Y_{Top}) for varying COV(k) in hinged head long (10T) pile group with spacing (3D).

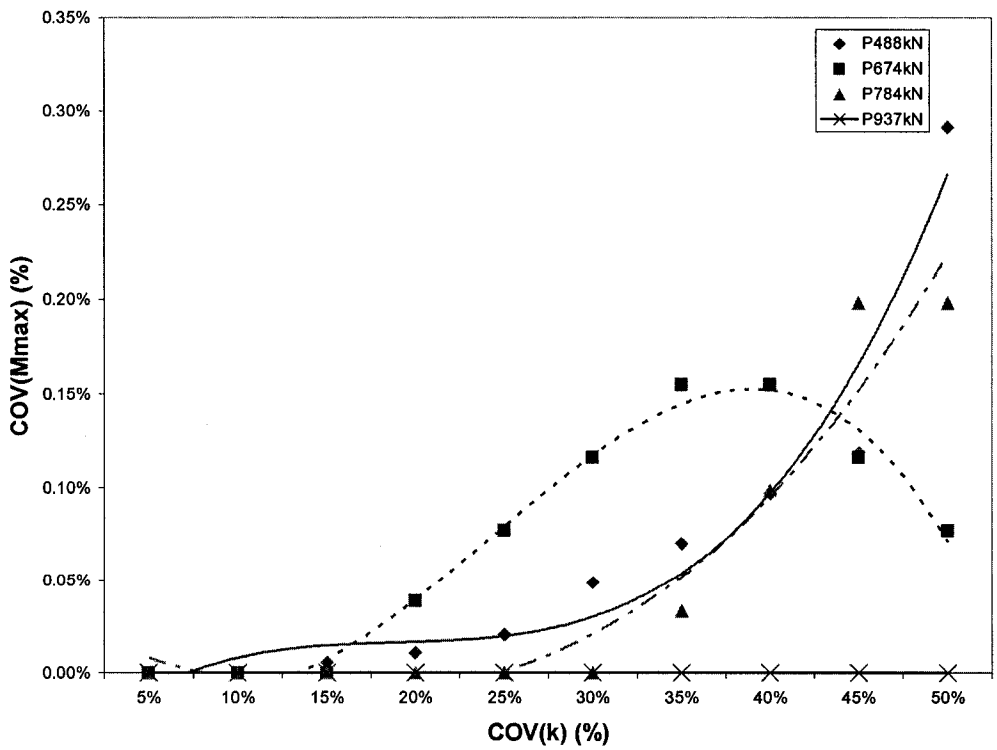

Fig. G.10(a) COV(M_{Max}) for varying COV(k) for pile C in hinged head long pile group with spacing (3D).

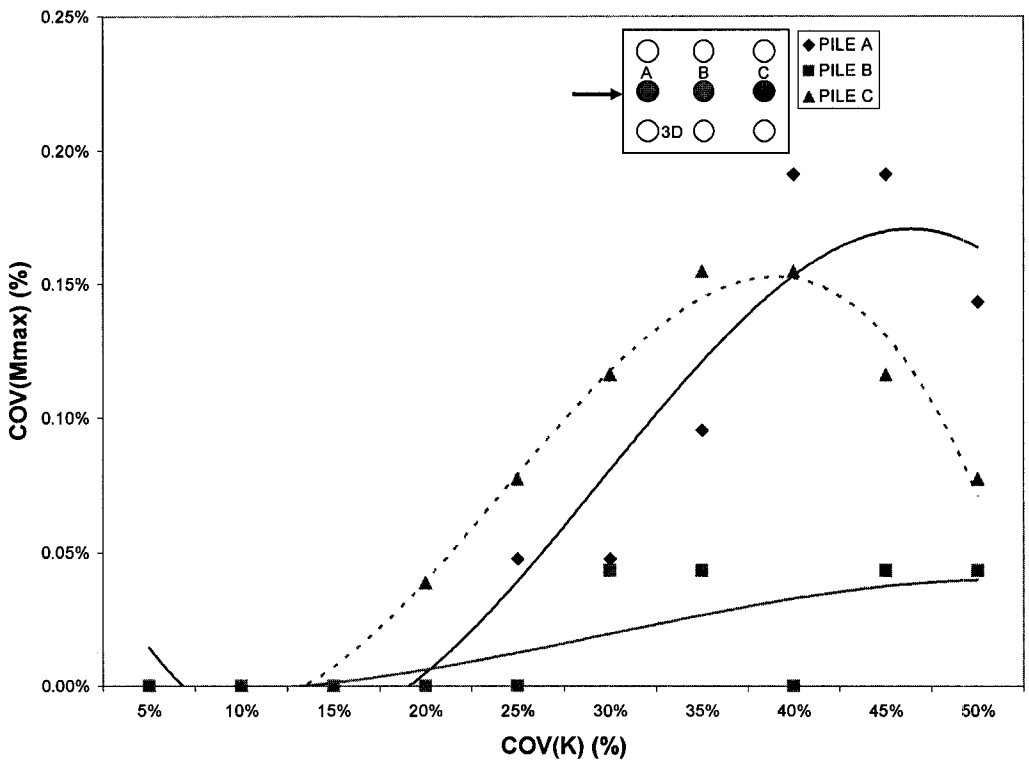

Fig. G.10(b) COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (3D) at the optimum lateral load 817 kN.

G.1.6 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (3D) and with 'k' as varying random design variable

Table G.21. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 589 kN and 817 kN.

			P=589 kN (59, 65, 72 kN)				**P=817 kN** (82, 90, 100 kN)			
			Ytop (m)	**Mmax (kN-m)**			**Ytop (m)**	**Mmax (kN-m)**		
COV(γ') (%)	**Var(γ') $(kN/m^3)^2$**	**γ' current (kN/m^3)**	**A/B/C**	**A**	**B**	**C**	**A/B/C**	**A**	**B**	**C**
50%	8.7025	2.95	0.00303	75.87	83.01	92.7	0.00476	104.6	115.1	129.2
45%	7.049025	3.245	0.00303	75.87	83.01	92.7	0.00476	104.6	115.1	129.2
40%	5.5696	3.54	0.00303	75.87	83.01	92.7	0.00476	104.6	115.1	129.2
35%	4.264225	3.835	0.00303	75.87	83.01	92.7	0.00476	104.6	115.1	129.2
30%	3.1329	4.13	0.00303	75.87	83.01	92.7	0.00475	104.6	115.1	129.2
25%	2.175625	4.425	0.00303	75.87	83.01	92.7	0.00475	104.6	115.1	129.2
20%	1.3924	4.72	0.00303	75.87	83.01	92.7	0.00475	104.6	115.1	129.2
15%	0.783225	5.015	0.00302	75.87	83.01	92.7	0.00475	104.6	115.1	129.2
10%	0.3481	5.31	0.00302	75.88	83	92.7	0.00475	104.6	115.1	129.2
5%	0.087025	5.605	0.00302	75.88	83	92.7	0.00474	104.6	115.1	129.2
0%	0	5.9	0.00302	75.88	83	92.7	0.00474	104.7	115.1	129.2
5%	0.087025	6.195	0.00302	75.88	82.99	92.7	0.00474	104.7	115.1	129.2
10%	0.3481	6.49	0.00302	75.88	82.99	92.7	0.00474	104.7	115.1	129.2
15%	0.783225	6.785	0.00302	75.88	82.99	92.7	0.00474	104.7	115.1	129.2
20%	1.3924	7.08	0.00302	75.88	82.99	92.7	0.00474	104.7	115.1	129.2
25%	2.175625	7.375	0.00301	75.88	82.99	92.7	0.00473	104.7	115.1	129.2
30%	3.1329	7.67	0.00301	75.88	82.99	92.7	0.00473	104.7	115.1	129.2
35%	4.264225	7.965	0.00301	75.88	82.99	92.7	0.00473	104.7	115.1	129.2
40%	5.5696	8.26	0.00301	75.88	82.99	92.7	0.00473	104.7	115.1	129.2
45%	7.049025	8.555	0.00301	75.88	82.99	92.7	0.00473	104.7	115.1	129.2
50%	8.7025	8.85	0.00301	75.88	82.99	92.7	0.00472	104.7	115.1	129.2

Table G.22. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 953 kN and 1142 kN.

			P=953 kN(95, 100, 120 kN)				P=1142 kN(110,130,140 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00598	121.4	134.1	151.5	0.008	145	160.6	182.1
45%	7.049025	3.245	0.00597	121.4	134.1	151.5	0.008	145	160.6	182.1
40%	5.5696	3.54	0.00597	121.4	134.1	151.5	0.00799	145	160.6	182.1
35%	4.264225	3.835	0.00597	121.4	134.1	151.5	0.00799	145	160.6	182.1
30%	3.1329	4.13	0.00597	121.4	134.1	151.5	0.00799	145	160.6	182.1
25%	2.175625	4.425	0.00596	121.4	134.1	151.5	0.00798	145	160.6	182.1
20%	1.3924	4.72	0.00596	121.4	134.1	151.5	0.00798	145	160.6	182.1
15%	0.783225	5.015	0.00596	121.4	134.1	151.5	0.00798	145	160.6	182.1
10%	0.3481	5.31	0.00596	121.4	134.1	151.5	0.00797	145	160.6	182.1
5%	0.087025	5.605	0.00595	121.4	134.1	151.5	0.00797	145	160.6	182.1
0%	0	5.9	0.00595	121.4	134.1	151.5	0.00797	145	160.6	182.1
5%	0.087025	6.195	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
10%	0.3481	6.49	0.00595	121.4	134.1	151.5	0.00796	145	160.6	182.1
15%	0.783225	6.785	0.00594	121.4	134.1	151.5	0.00795	145	160.6	182.1
20%	1.3924	7.08	0.00594	121.4	134.1	151.5	0.00795	145	160.6	182.1
25%	2.175625	7.375	0.00594	121.4	134.1	151.5	0.00795	145	160.6	182.1
30%	3.1329	7.67	0.00593	121.4	134.1	151.5	0.00794	145	160.6	182.1
35%	4.264225	7.965	0.00593	121.4	134.1	151.5	0.00794	145	160.6	182.1
40%	5.5696	8.26	0.00593	121.4	134.1	151.5	0.00794	145	160.6	182.1
45%	7.049025	8.555	0.00593	121.4	134.1	151.5	0.00793	145	160.6	182.1
50%	8.7025	8.85	0.00592	121.4	134.1	151.5	0.00793	145	160.6	182.1

Table G.23(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 589 kN and 817 kN.

		P=589 kN		P=817 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	0.00E+00	0.000%
10%	3.48E-01	0.00E+00	0.000%	2.50E-11	0.105%
15%	7.83E-01	0.00E+00	0.000%	2.50E-11	0.105%
20%	1.39E+00	2.50E-11	0.166%	2.50E-11	0.105%
25%	2.18E+00	1.00E-10	0.331%	1.00E-10	0.211%
30%	3.13E+00	1.00E-10	0.331%	1.00E-10	0.211%
35%	4.26E+00	1.00E-10	0.331%	2.25E-10	0.316%
40%	5.57E+00	1.00E-10	0.331%	2.25E-10	0.316%
45%	7.05E+00	1.00E-10	0.331%	2.25E-10	0.316%
50%	8.70E+00	1.00E-10	0.331%	4.00E-10	0.422%

Table G.23(b) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 953 kN and 1142 kN.

		P=953 kN		P=1142 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	2.50E-11	0.063%
10%	3.48E-01	2.50E-11	0.084%	2.50E-11	0.063%
15%	7.83E-01	1.00E-10	0.168%	2.25E-10	0.188%
20%	1.39E+00	1.00E-10	0.168%	2.25E-10	0.188%
25%	2.18E+00	1.00E-10	0.168%	2.25E-10	0.188%
30%	3.13E+00	4.00E-10	0.336%	6.25E-10	0.314%
35%	4.26E+00	4.00E-10	0.336%	6.25E-10	0.314%
40%	5.57E+00	4.00E-10	0.336%	6.25E-10	0.314%
45%	7.05E+00	4.00E-10	0.336%	1.23E-09	0.439%
50%	8.70E+00	9.00E-10	0.504%	1.23E-09	0.439%

Table G.24(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'γ' and lateral load 589 kN.

		P=589 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	8.70E-02	0.00E+00	2.50E-05	0.00E+00	0.00%	0.01%	0.00%
10%	3.48E-01	0.00E+00	2.50E-05	0.00E+00	0.00%	0.01%	0.00%
15%	7.83E-01	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
20%	1.39E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
25%	2.18E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
30%	3.13E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
35%	4.26E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
40%	5.57E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
45%	7.05E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
50%	8.70E+00	2.50E-05	1.00E-04	0.00E+00	0.01%	0.01%	0.00%

Table G.24(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'γ' and lateral load 817 kN.

		P=817 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	8.70E-02	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
10%	3.48E-01	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
15%	7.83E-01	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
20%	1.39E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
25%	2.18E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
30%	3.13E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
35%	4.26E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
40%	5.57E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
45%	7.05E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
50%	8.70E+00	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%

Table G.24(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'γ' and lateral load 953 kN.

		P=953 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	8.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	3.48E-01	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	7.83E-01	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.39E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.18E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.13E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.26E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.57E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	7.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
50%	8.70E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%

Table G.24(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (3D) and with varying 'γ' and lateral load 953 kN.

		P=1142 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	8.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	3.48E-01	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	7.83E-01	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.39E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.18E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.13E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.26E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.57E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	7.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
50%	8.70E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%

Note: Value of COV(M_{MAX}) is zero for pile row C with varying COV(γ') in hinged head long (10T) pile group with spacing (3D).

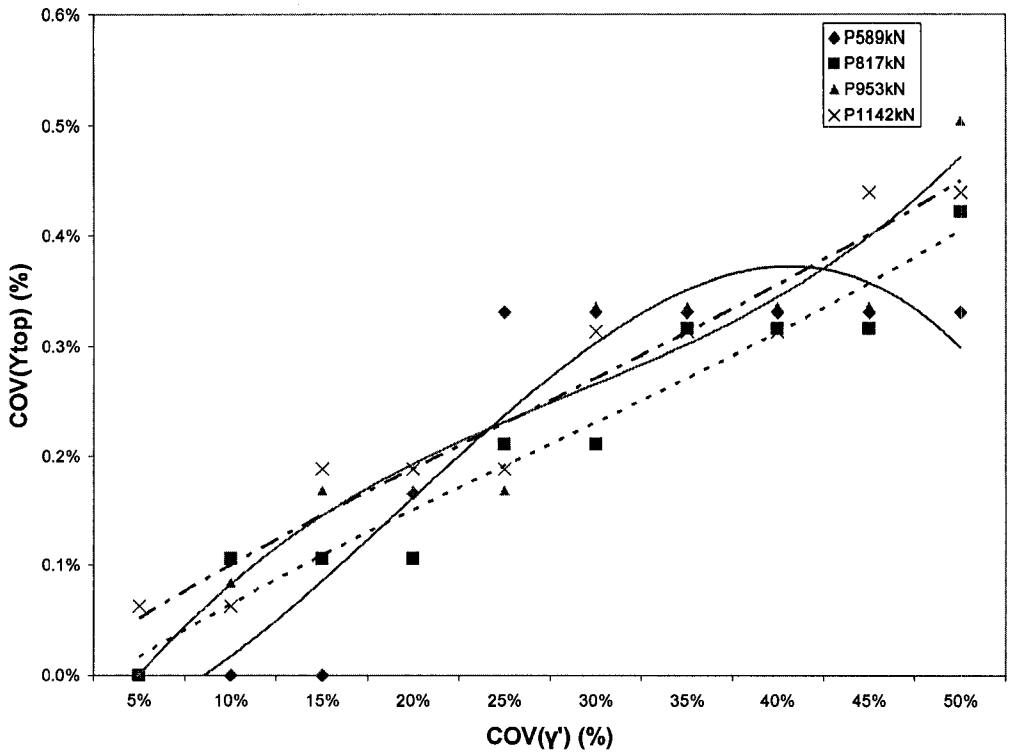

Fig. G.11 COV(Y_{Top}) for varying COV(γ') in hinged head long (10T) pile group with spacing (3D).

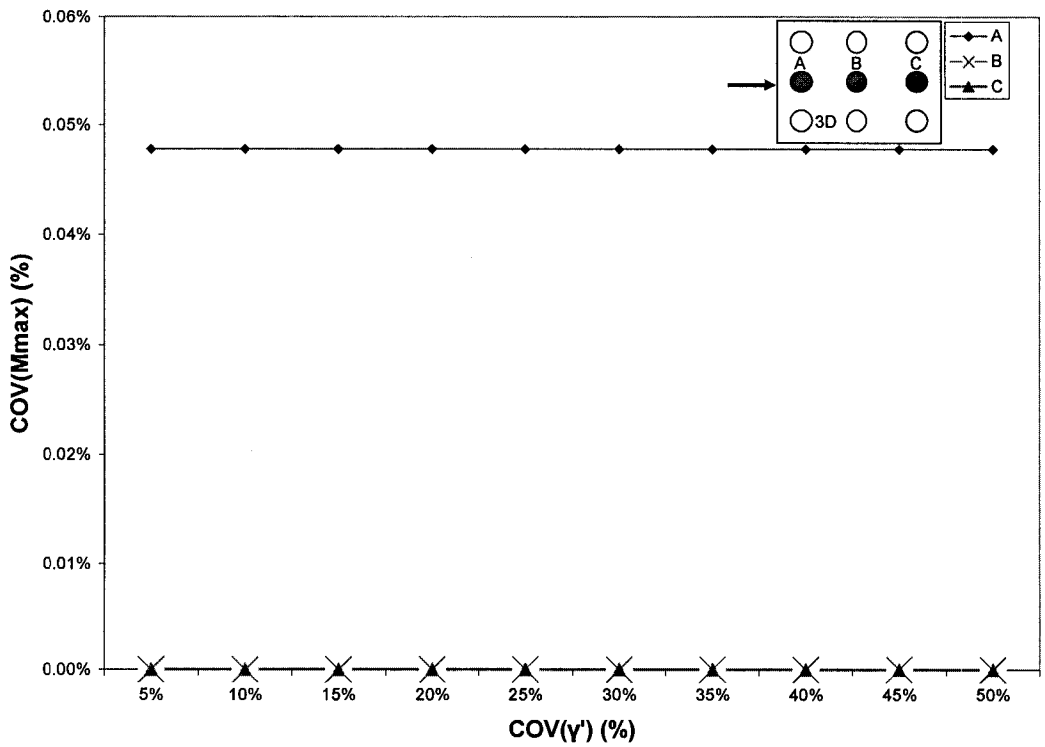

Fig. G.12 COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (3D) at the optimum lateral load 817 kN.

G.2 Reliability analysis of hinged head long pile (10T) group with spacing (3D)

G.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 589 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00998 \text{ m} \quad \text{and} \quad VAR(Y_{top}^{Resist}) = 6.76E\text{-}06 \text{ m}^2$$

Table G.25 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 589 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	9.00E-10	6.76E-06	3.84	1.10E-08	6.76E-06	3.84
10%	6.76E-06	2.02E-09	6.76E-06	3.84	4.84E-08	6.76E-06	3.84
15%	6.76E-06	4.90E-09	6.76E-06	3.84	1.12E-07	6.76E-06	3.84
20%	6.76E-06	7.23E-09	6.77E-06	3.84	2.12E-07	6.77E-06	3.84
25%	6.76E-06	3.60E-09	6.76E-06	3.84	3.54E-07	6.76E-06	3.84
30%	6.76E-06	4.00E-10	6.76E-06	3.84	5.48E-07	6.76E-06	3.84
35%	6.76E-06	6.25E-10	6.76E-06	3.84	8.01E-07	6.76E-06	3.84
40%	6.76E-06	5.63E-09	6.77E-06	3.84	1.17E-06	6.77E-06	3.84
45%	6.76E-06	1.96E-08	6.78E-06	3.83	1.69E-06	6.78E-06	3.83
50%	6.76E-06	5.76E-08	6.82E-06	3.82	2.45E-06	6.82E-06	3.82

Table G.26 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and 'EI' and applied lateral load 589 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	3.60E-09	6.76E-06	3.84	7.46E-09	6.77E-06	3.84
10%	6.76E-06	1.10E-08	6.77E-06	3.84	2.68E-08	6.79E-06	3.83
15%	6.76E-06	2.56E-08	6.79E-06	3.83	6.71E-08	6.83E-06	3.82
20%	6.76E-06	4.62E-08	6.81E-06	3.83	1.23E-07	6.88E-06	3.80
25%	6.76E-06	7.56E-08	6.84E-06	3.82	2.03E-07	6.96E-06	3.78
30%	6.76E-06	1.12E-07	6.87E-06	3.81	3.03E-07	7.06E-06	3.76
35%	6.76E-06	1.52E-07	6.91E-06	3.80	4.34E-07	7.19E-06	3.72
40%	6.76E-06	2.12E-07	6.97E-06	3.78	6.04E-07	7.36E-06	3.68
45%	6.76E-06	2.70E-07	7.03E-06	3.76	8.26E-07	7.59E-06	3.62
50%	6.76E-06	3.48E-07	7.11E-06	3.74	1.10E-06	7.86E-06	3.56

Table G.27 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 589 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.84	0.00E+00	6.76E-06	3.84
10%	6.76E-06	0.00E+00	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
15%	6.76E-06	0.00E+00	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
20%	6.76E-06	2.50E-11	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
25%	6.76E-06	1.00E-10	6.76E-06	3.84	2.25E-10	6.76E-06	3.84
30%	6.76E-06	1.00E-10	6.76E-06	3.84	4.00E-10	6.76E-06	3.84
35%	6.76E-06	1.00E-10	6.76E-06	3.84	6.25E-10	6.76E-06	3.84
40%	6.76E-06	1.00E-10	6.76E-06	3.84	1.22E-09	6.76E-06	3.84
45%	6.76E-06	1.00E-10	6.76E-06	3.84	1.60E-09	6.76E-06	3.84
50%	6.76E-06	1.00E-10	6.76E-06	3.84	3.02E-09	6.76E-06	3.84

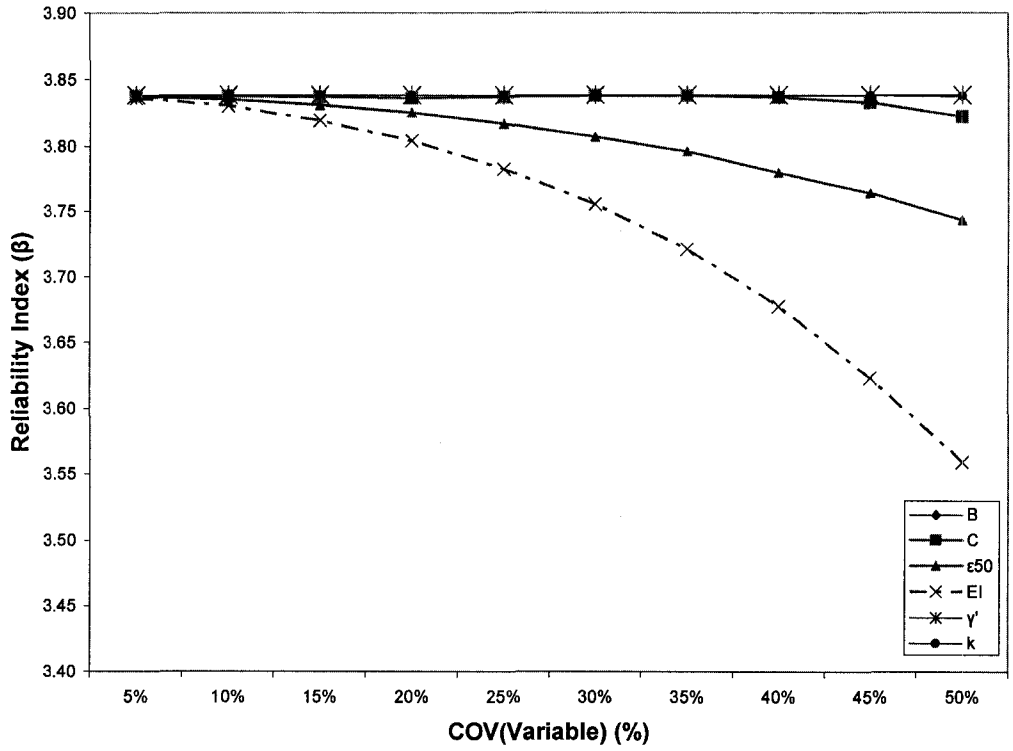

Fig. G.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in free head long (10T) pile group with spacing (3D) at 589 kN lateral load.

For lateral load 817 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00826 \text{ m}$$

Table G.28 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 817 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	1.60E-09	6.76E-06	3.18	3.42E-08	6.79E-06	3.17
10%	6.76E-06	3.60E-09	6.76E-06	3.18	1.41E-07	6.90E-06	3.14
15%	6.76E-06	8.10E-09	6.77E-06	3.18	3.36E-07	7.10E-06	3.10
20%	6.76E-06	1.44E-08	6.77E-06	3.17	6.48E-07	7.41E-06	3.03
25%	6.76E-06	1.60E-09	6.76E-06	3.18	1.09E-06	7.85E-06	2.95
30%	6.76E-06	3.60E-09	6.76E-06	3.18	1.74E-06	8.50E-06	2.83
35%	6.76E-06	3.24E-08	6.79E-06	3.17	2.66E-06	9.42E-06	2.69
40%	6.76E-06	1.09E-07	6.87E-06	3.15	3.94E-06	1.07E-05	2.53
45%	6.76E-06	2.65E-07	7.03E-06	3.12	5.69E-06	1.24E-05	2.34
50%	6.76E-06	6.08E-07	7.37E-06	3.04	8.38E-06	1.51E-05	2.12

Table G.29 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and 'EI' and applied lateral load 817 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	9.02E-09	6.77E-06	3.17	1.62E-08	6.78E-06	3.17
10%	6.76E-06	3.61E-08	6.80E-06	3.17	6.48E-08	6.82E-06	3.16
15%	6.76E-06	8.12E-08	6.84E-06	3.16	1.60E-07	6.92E-06	3.14
20%	6.76E-06	1.44E-07	6.90E-06	3.14	2.93E-07	7.05E-06	3.11
25%	6.76E-06	2.21E-07	6.98E-06	3.13	4.65E-07	7.22E-06	3.07
30%	6.76E-06	3.14E-07	7.07E-06	3.11	7.00E-07	7.46E-06	3.02
35%	6.76E-06	4.23E-07	7.18E-06	3.08	1.02E-06	7.78E-06	2.96
40%	6.76E-06	5.55E-07	7.32E-06	3.05	1.44E-06	8.20E-06	2.88
45%	6.76E-06	7.06E-07	7.47E-06	3.02	1.99E-06	8.75E-06	2.79
50%	6.76E-06	8.74E-07	7.63E-06	2.99	2.71E-06	9.47E-06	2.68

Table G.30 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 817 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.18	0.00E+00	6.76E-06	3.18
10%	6.76E-06	2.50E-11	6.76E-06	3.18	0.00E+00	6.76E-06	3.18
15%	6.76E-06	2.50E-11	6.76E-06	3.18	0.00E+00	6.76E-06	3.18
20%	6.76E-06	2.50E-11	6.76E-06	3.18	2.50E-11	6.76E-06	3.18
25%	6.76E-06	1.00E-10	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
30%	6.76E-06	1.00E-10	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
35%	6.76E-06	2.25E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
40%	6.76E-06	2.25E-10	6.76E-06	3.18	4.00E-10	6.76E-06	3.18
45%	6.76E-06	2.25E-10	6.76E-06	3.18	1.22E-09	6.76E-06	3.18
50%	6.76E-06	4.00E-10	6.76E-06	3.18	2.02E-09	6.76E-06	3.18

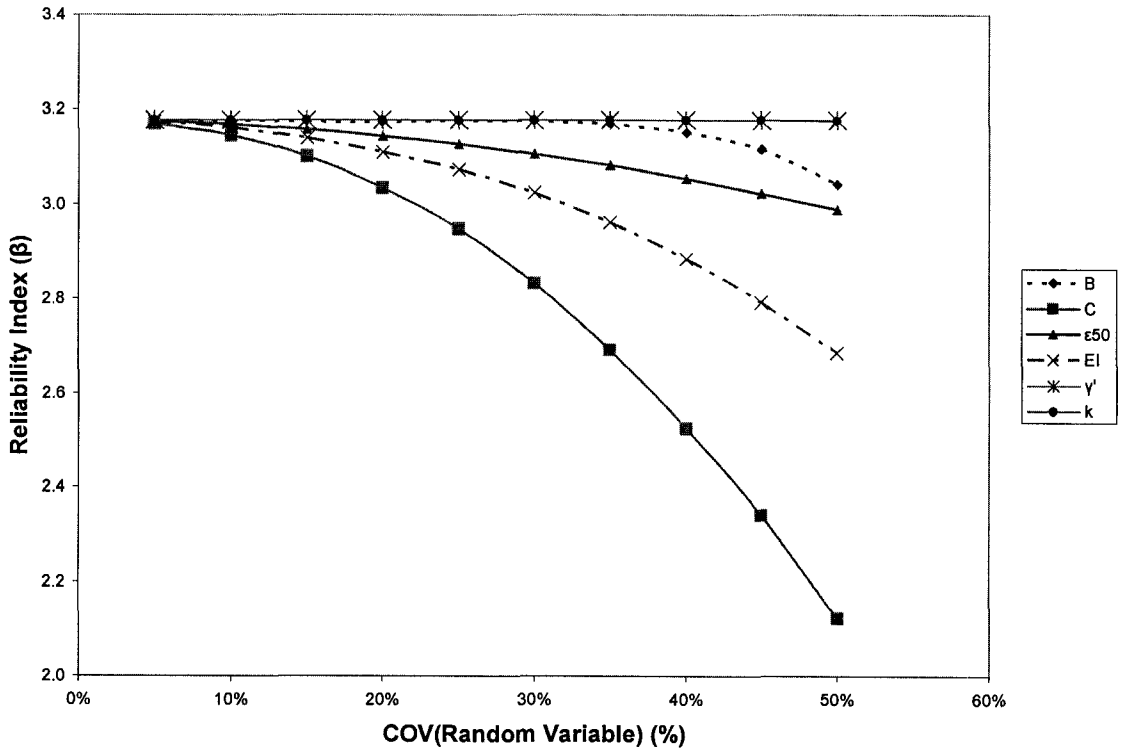

Fig. G.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (3D) at 817 kN lateral load.

For lateral load 953 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00705 \text{ m}$$

Table G.31 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 953 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	1.22E-09	6.76E-06	2.71	7.56E-08	6.84E-06	2.70
10%	6.76E-06	9.00E-10	6.76E-06	2.71	3.03E-07	7.06E-06	2.65
15%	6.76E-06	2.50E-09	6.76E-06	2.71	7.06E-07	7.47E-06	2.58
20%	6.76E-06	4.23E-09	6.76E-06	2.71	1.31E-06	8.07E-06	2.48
25%	6.76E-06	3.60E-09	6.76E-06	2.71	2.19E-06	8.95E-06	2.36
30%	6.76E-06	4.20E-08	6.80E-06	2.70	3.39E-06	1.01E-05	2.21
35%	6.76E-06	1.52E-07	6.91E-06	2.68	5.11E-06	1.19E-05	2.05
40%	6.76E-06	3.91E-07	7.15E-06	2.64	7.32E-06	1.41E-05	1.88
45%	6.76E-06	8.74E-07	7.63E-06	2.55	1.10E-05	1.77E-05	1.67
50%	6.76E-06	1.95E-06	8.71E-06	2.39	1.57E-05	2.25E-05	1.49

Table G.32 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and 'EI' and applied lateral load 953 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	1.21E-08	6.77E-06	2.71	2.98E-08	6.79E-06	2.71
10%	6.76E-06	4.62E-08	6.81E-06	2.70	1.19E-07	6.88E-06	2.69
15%	6.76E-06	1.06E-07	6.87E-06	2.69	2.73E-07	7.03E-06	2.66
20%	6.76E-06	1.98E-07	6.96E-06	2.67	4.96E-07	7.26E-06	2.62
25%	6.76E-06	2.97E-07	7.06E-06	2.65	8.02E-07	7.56E-06	2.56
30%	6.76E-06	4.49E-07	7.21E-06	2.63	1.20E-06	7.96E-06	2.50
35%	6.76E-06	6.16E-07	7.38E-06	2.60	1.73E-06	8.49E-06	2.42
40%	6.76E-06	7.92E-07	7.55E-06	2.57	2.43E-06	9.19E-06	2.33
45%	6.76E-06	1.01E-06	7.77E-06	2.53	3.39E-06	1.01E-05	2.21
50%	6.76E-06	1.24E-06	8.00E-06	2.49	4.60E-06	1.14E-05	2.09

Table G.33 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 953 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
10%	6.76E-06	2.50E-11	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
15%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
20%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
25%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
30%	6.76E-06	4.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
35%	6.76E-06	4.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
40%	6.76E-06	4.00E-10	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
45%	6.76E-06	4.00E-10	6.76E-06	2.71	1.00E-10	6.76E-06	2.71
50%	6.76E-06	9.00E-10	6.76E-06	2.71	9.00E-10	6.76E-06	2.71

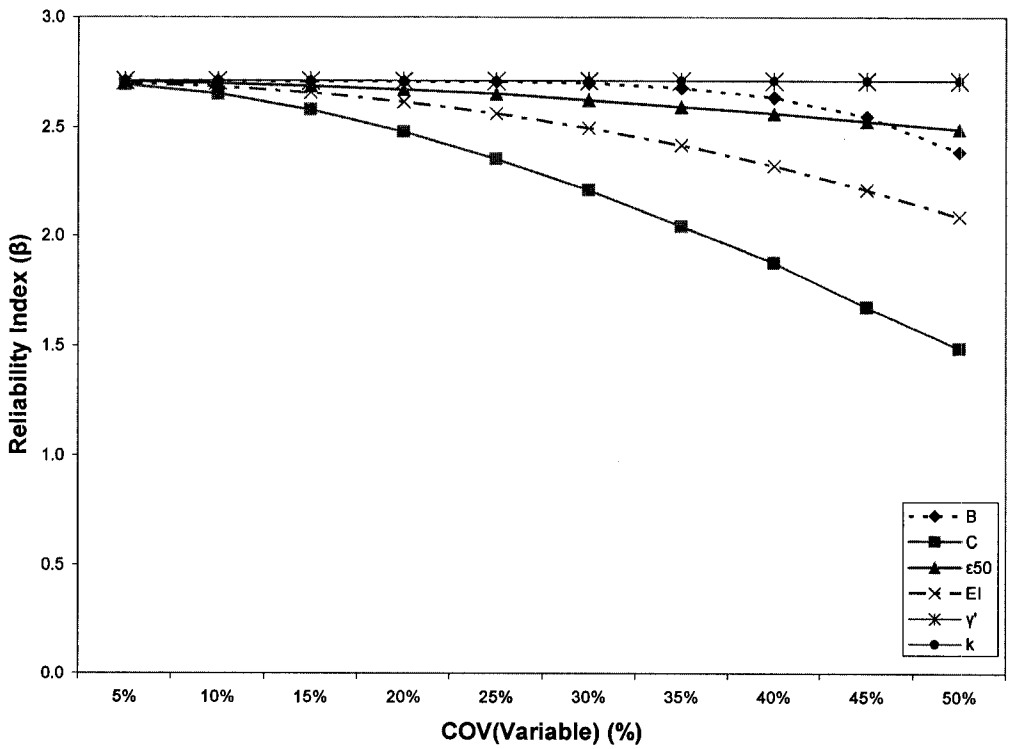

Fig. G.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (3D) at 953 kN lateral load.

For lateral load 1142 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00503 \text{ m}$$

Table G.34 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 1142 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	1.93	1.68E-07	6.93E-06	1.91
10%	6.76E-06	2.50E-11	6.76E-06	1.93	6.64E-07	7.42E-06	1.85
15%	6.76E-06	0.00E+00	6.76E-06	1.93	1.56E-06	8.32E-06	1.74
20%	6.76E-06	2.25E-10	6.76E-06	1.93	2.91E-06	9.67E-06	1.62
25%	6.76E-06	5.76E-08	6.82E-06	1.93	4.97E-06	1.17E-05	1.47
30%	6.76E-06	2.50E-07	7.01E-06	1.90	7.76E-06	1.45E-05	1.32
35%	6.76E-06	7.14E-07	7.47E-06	1.84	1.15E-05	1.82E-05	1.18
40%	6.76E-06	1.76E-06	8.52E-06	1.72	1.70E-05	2.37E-05	1.03
45%	6.76E-06	4.33E-06	1.11E-05	1.51	2.59E-05	3.27E-05	0.88
50%	6.76E-06	2.07E-05	2.74E-05	0.96	4.18E-05	4.86E-05	0.72

Table G.35 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1142 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.40E-08	6.78E-06	1.93	5.59E-08	6.82E-06	1.93
10%	6.76E-06	8.41E-08	6.84E-06	1.92	2.19E-07	6.98E-06	1.90
15%	6.76E-06	1.81E-07	6.94E-06	1.91	4.96E-07	7.26E-06	1.87
20%	6.76E-06	3.19E-07	7.08E-06	1.89	9.20E-07	7.68E-06	1.82
25%	6.76E-06	4.90E-07	7.25E-06	1.87	1.50E-06	8.26E-06	1.75
30%	6.76E-06	7.14E-07	7.47E-06	1.84	2.21E-06	8.97E-06	1.68
35%	6.76E-06	9.90E-07	7.75E-06	1.81	3.36E-06	1.01E-05	1.58
40%	6.76E-06	1.29E-06	8.05E-06	1.77	4.70E-06	1.15E-05	1.49
45%	6.76E-06	1.64E-06	8.40E-06	1.74	6.50E-06	1.33E-05	1.38
50%	6.76E-06	2.02E-06	8.78E-06	1.70	8.84E-06	1.56E-05	1.27

Table G.36 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 1142 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
10%	6.76E-06	2.50E-11	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
15%	6.76E-06	2.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
20%	6.76E-06	2.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
25%	6.76E-06	2.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
30%	6.76E-06	6.25E-10	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
35%	6.76E-06	6.25E-10	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
40%	6.76E-06	6.25E-10	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
45%	6.76E-06	1.23E-09	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
50%	6.76E-06	1.23E-09	6.76E-06	1.93	2.50E-11	6.76E-06	1.93

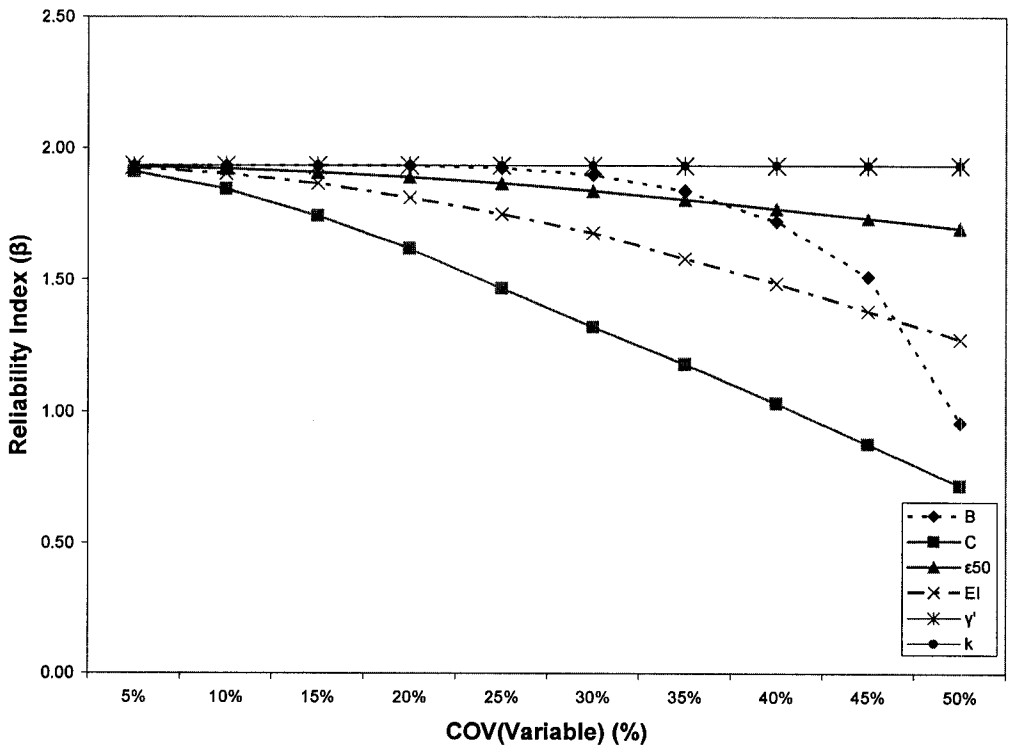

Fig. G.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (3D) at 1142 kN lateral load.

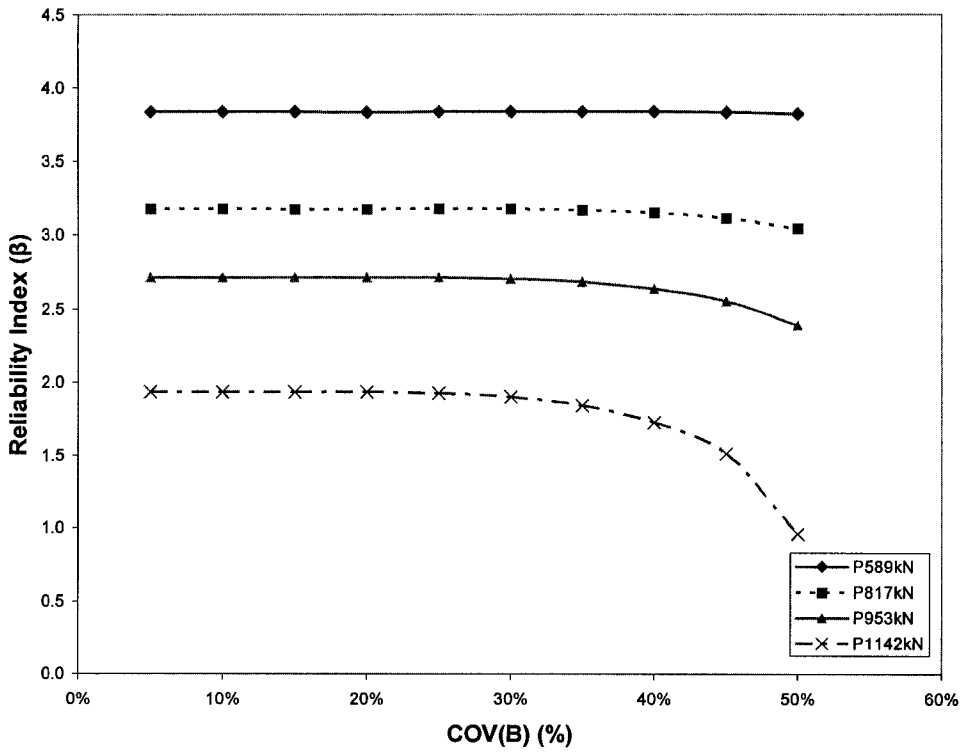

Fig. G.17 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'B'.

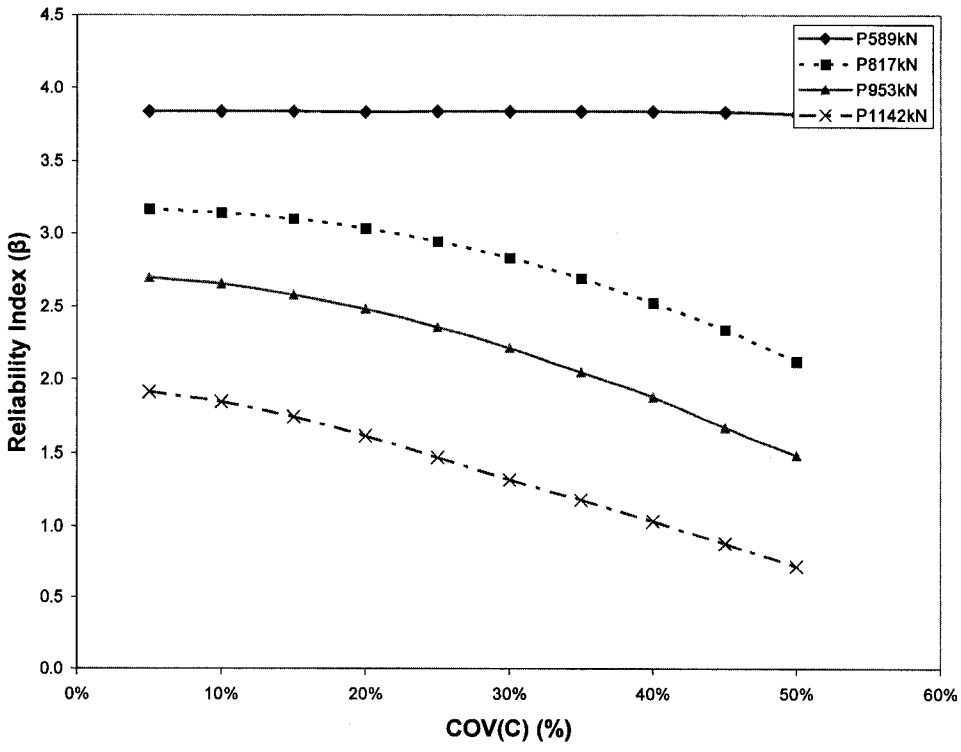

Fig. G.18 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'C'.

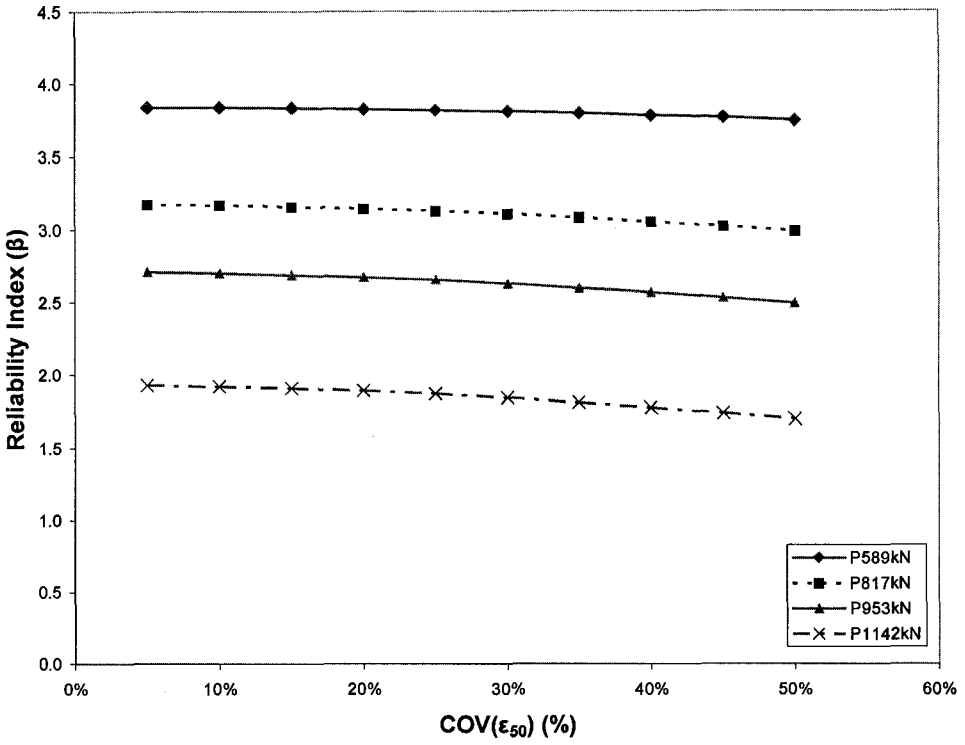

Fig. G.19 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}'.

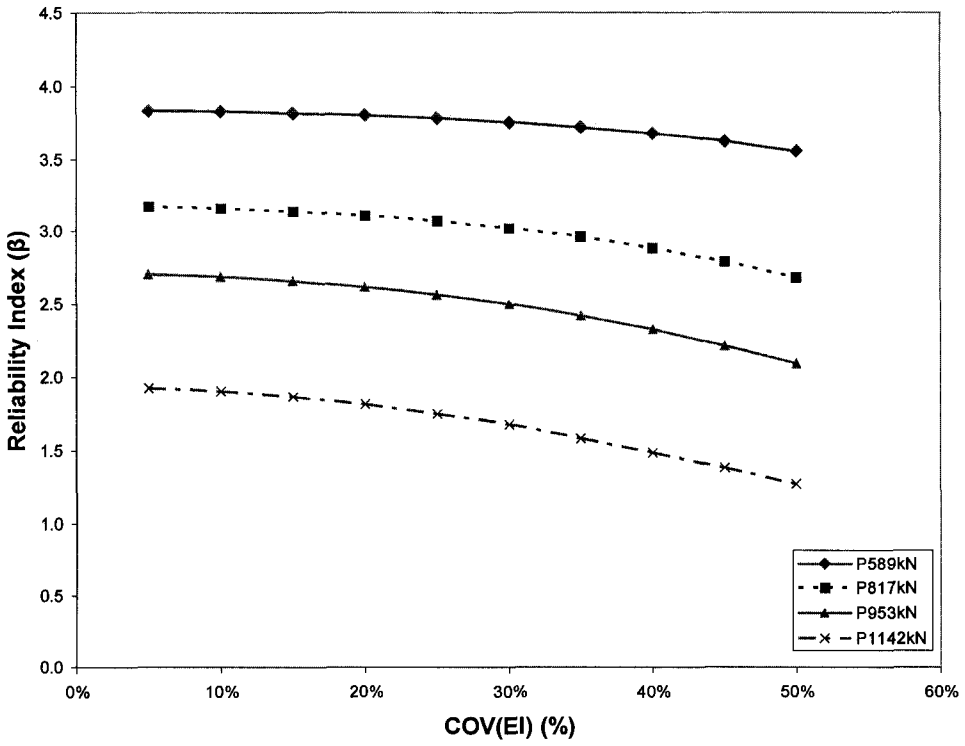

Fig. G.20 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'EI'.

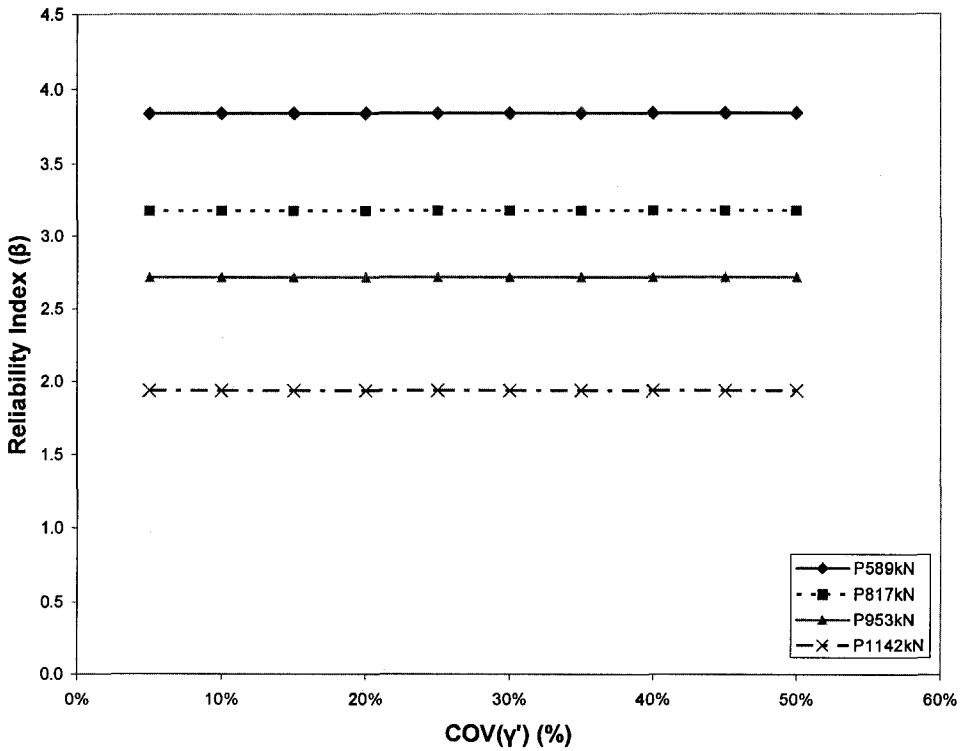

Fig. G.21 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'γ'.

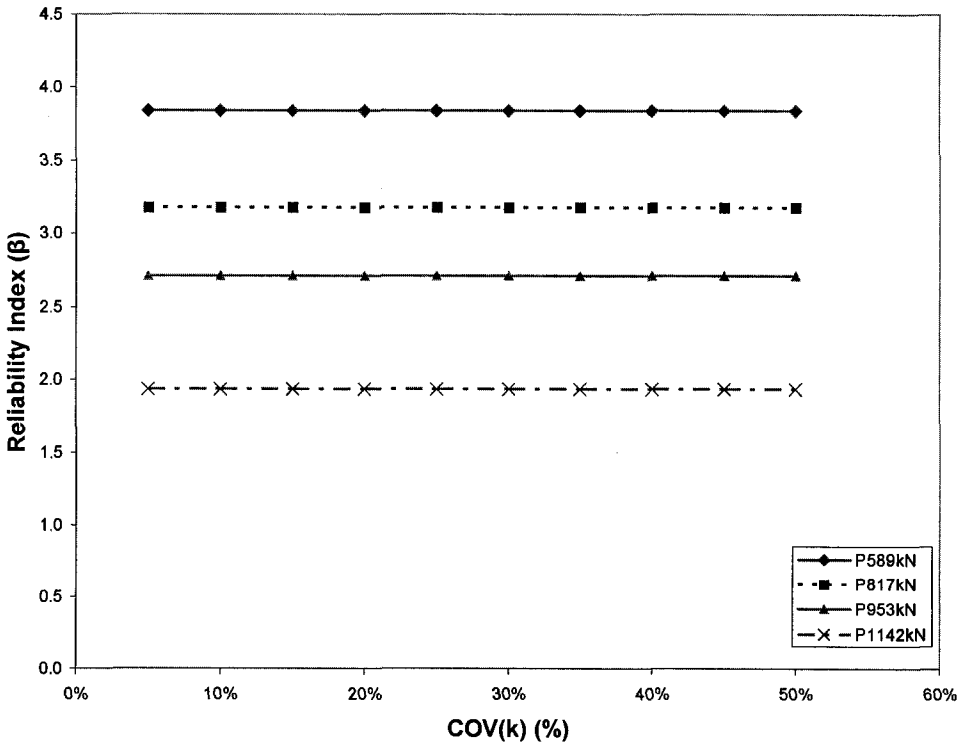

Fig. G.22 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (3D) and with varying 'k'.

G.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 589 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 801.3 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table G.37 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 589 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0016	31969.442	4.48	0.0036	31969.444	4.48
10%	31969.44	0.0064	31969.446	4.48	0.021025	31969.461	4.48
15%	31969.44	0.0121	31969.452	4.48	0.0361	31969.476	4.48
20%	31969.44	0.021025	31969.461	4.48	0.0484	31969.488	4.48
25%	31969.44	0.01369	31969.454	4.48	0.03136	31969.471	4.48
30%	31969.44	0.065025	31969.505	4.48	0.112225	31969.552	4.48
35%	31969.44	0.1225	31969.563	4.48	0.1521	31969.592	4.48
40%	31969.44	0.1936	31969.634	4.48	0.2209	31969.661	4.48
45%	31969.44	0.403225	31969.843	4.48	0.378225	31969.818	4.48
50%	31969.44	0.6084	31970.048	4.48	0.4489	31969.889	4.48

Table G.38 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying ε_{50} and EI and applied lateral load 589 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.003025	31969.443	4.48	0.0003306	31969.440	4.48
10%	31969.44	0.0025	31969.443	4.48	0.0040496	31969.444	4.48
15%	31969.44	0.0064	31969.446	4.48	0.0059711	31969.446	4.48
20%	31969.44	0.0121	31969.452	4.48	0.0109298	31969.451	4.48
25%	31969.44	0.00729	31969.447	4.48	0.0033058	31969.443	4.48
30%	31969.44	0.0225	31969.463	4.48	0.0129132	31969.453	4.48
35%	31969.44	0.027225	31969.467	4.48	0.018595	31969.459	4.48
40%	31969.44	0.0289	31969.469	4.48	0.0253099	31969.465	4.48
45%	31969.44	0.0324	31969.472	4.48	0.0314256	31969.471	4.48
50%	31969.44	0.038025	31969.478	4.48	0.0418388	31969.482	4.48

Table G.39 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 589 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.440	4.48	0	31969.440	4.48
10%	31969.44	0.00E+00	31969.440	4.48	0	31969.440	4.48
15%	31969.44	0.00E+00	31969.440	4.48	2.5E-05	31969.440	4.48
20%	31969.44	0.00E+00	31969.440	4.48	1E-04	31969.440	4.48
25%	31969.44	0.00E+00	31969.440	4.48	0.00036	31969.440	4.48
30%	31969.44	0.00E+00	31969.440	4.48	0.002025	31969.442	4.48
35%	31969.44	0.00E+00	31969.440	4.48	0.004225	31969.444	4.48
40%	31969.44	0.00E+00	31969.440	4.48	0.0081	31969.448	4.48
45%	31969.44	0.00E+00	31969.440	4.48	0.0121	31969.452	4.48
50%	31969.44	0.00E+00	31969.440	4.48	0.0729	31969.513	4.48

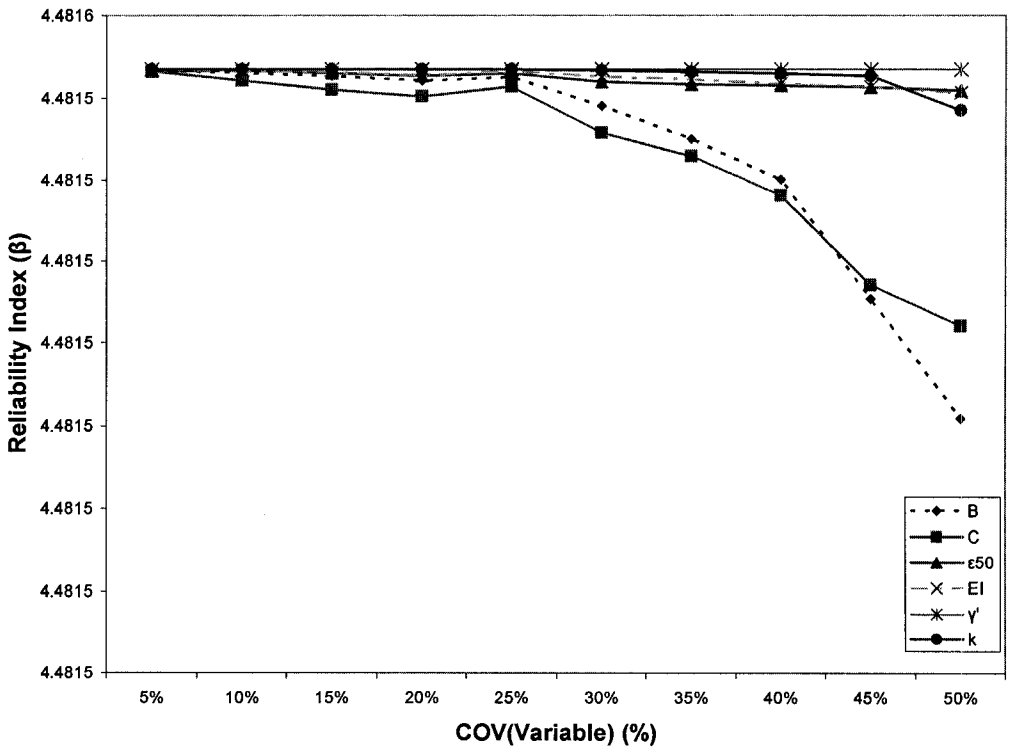

Fig. G.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (3D) at 589 kN lateral load.

For lateral load 817 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 764.8 \text{ kN.m}$$

Table G.40 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 817 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.28	0.0225	31969.46	4.28
10%	31969.44	0.0025	31969.44	4.28	0.16	31969.60	4.28
15%	31969.44	0.0225	31969.46	4.28	0.49	31969.93	4.28
20%	31969.44	0.09	31969.53	4.28	0.64	31970.08	4.28
25%	31969.44	0.25	31969.69	4.28	0.81	31970.25	4.28
30%	31969.44	0.4225	31969.86	4.28	1	31970.44	4.28
35%	31969.44	0.64	31970.08	4.28	0.9025	31970.34	4.28
40%	31969.44	0.9025	31970.34	4.28	1	31970.44	4.28
45%	31969.44	1.1025	31970.54	4.28	13.69	31983.13	4.28
50%	31969.44	1.5625	31971.00	4.28	47.61	32017.05	4.27

Table G.41 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying ε_{50} and EI and applied lateral load 817 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.28	0.0020661	31969.44	4.28
10%	31969.44	0.0225	31969.46	4.28	0.0082645	31969.45	4.28
15%	31969.44	0.09	31969.53	4.28	0.018595	31969.46	4.28
20%	31969.44	0.16	31969.60	4.28	0.0330579	31969.47	4.28
25%	31969.44	0.16	31969.60	4.28	0.1012397	31969.54	4.28
30%	31969.44	0.16	31969.60	4.28	0.0743802	31969.51	4.28
35%	31969.44	0.1225	31969.56	4.28	0.1012397	31969.54	4.28
40%	31969.44	0.09	31969.53	4.28	0.1012397	31969.54	4.28
45%	31969.44	0.0625	31969.50	4.28	0.1673554	31969.61	4.28
50%	31969.44	0.04	31969.48	4.28	0.1673554	31969.61	4.28

Table G.42 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 817 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	4.28	0	31969.44	4.28
10%	31969.44	0.00E+00	31969.44	4.28	0	31969.44	4.28
15%	31969.44	0.00E+00	31969.44	4.28	0	31969.44	4.28
20%	31969.44	0.00E+00	31969.44	4.28	0.0025	31969.44	4.28
25%	31969.44	0.00E+00	31969.44	4.28	0.01	31969.45	4.28
30%	31969.44	0.00E+00	31969.44	4.28	0.0225	31969.46	4.28
35%	31969.44	0.00E+00	31969.44	4.28	0.04	31969.48	4.28
40%	31969.44	0.00E+00	31969.44	4.28	0.04	31969.48	4.28
45%	31969.44	0.00E+00	31969.44	4.28	0.0225	31969.46	4.28
50%	31969.44	0.00E+00	31969.44	4.28	0.01	31969.45	4.28

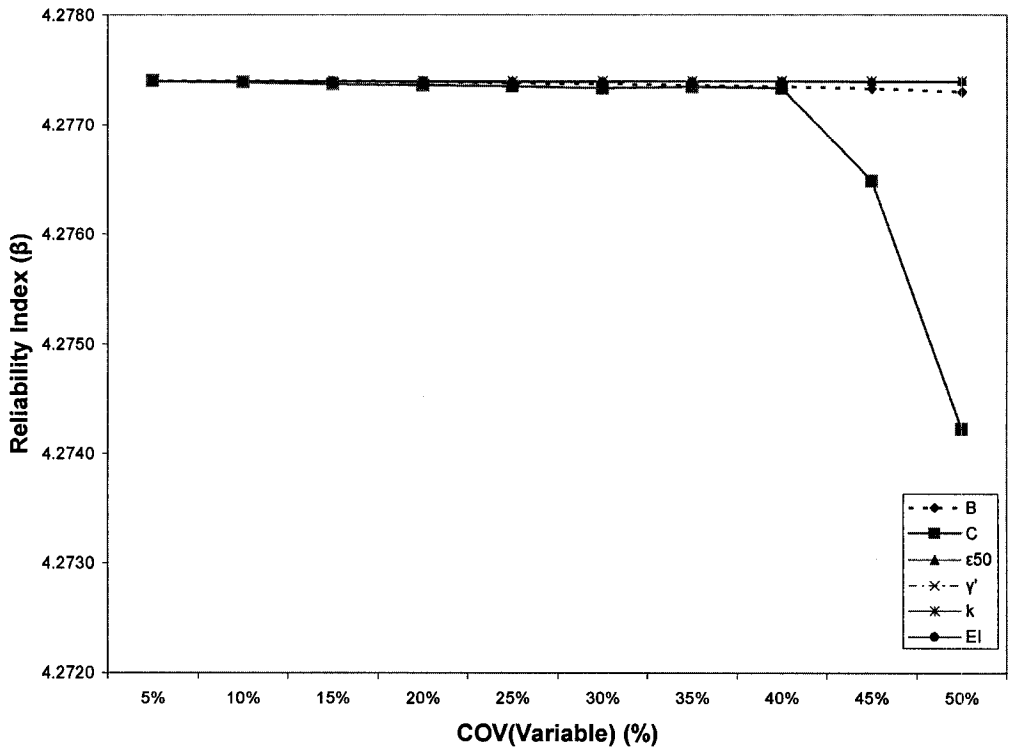

Fig. G.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (3D) at 817 kN lateral load.

For lateral load 953 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 742.5 \text{ kN.m}$$

Table G.43 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 953 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.01	31969.45	4.15	0.04	31969.48	4.15
10%	31969.44	0.04	31969.48	4.15	0.25	31969.69	4.15
15%	31969.44	0.1225	31969.56	4.15	0.64	31970.08	4.15
20%	31969.44	0.36	31969.80	4.15	1	31970.44	4.15
25%	31969.44	0.5625	31970.00	4.15	1.44	31970.88	4.15
30%	31969.44	0.81	31970.25	4.15	1.5625	31971.00	4.15
35%	31969.44	1.1025	31970.54	4.15	7.29	31976.73	4.15
40%	31969.44	1.44	31970.88	4.15	34.2225	32003.66	4.15
45%	31969.44	1.8225	31971.26	4.15	91.2025	32060.64	4.15
50%	31969.44	3.0625	31972.50	4.15	193.21	32162.65	4.14

Table G.44 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying ε_{50} and EI and applied lateral load 953 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.15	0	31969.44	4.15
10%	31969.44	0.0025	31969.44	4.15	0.0082645	31969.45	4.15
15%	31969.44	0.01	31969.45	4.15	0.0082645	31969.45	4.15
20%	31969.44	0.0225	31969.46	4.15	0.018595	31969.46	4.15
25%	31969.44	0.0225	31969.46	4.15	0.018595	31969.46	4.15
30%	31969.44	0.16	31969.60	4.15	0.0516529	31969.49	4.15
35%	31969.44	0.2025	31969.64	4.15	0.0743802	31969.51	4.15
40%	31969.44	0.25	31969.69	4.15	0.0743802	31969.51	4.15
45%	31969.44	0.25	31969.69	4.15	0.0743802	31969.51	4.15
50%	31969.44	0.16	31969.60	4.15	0.1322314	31969.57	4.15

Table G.45 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 953 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	4.15	0	31969.44	4.15
10%	31969.44	0.00E+00	31969.44	4.15	0	31969.44	4.15
15%	31969.44	0.00E+00	31969.44	4.15	0	31969.44	4.15
20%	31969.44	0.00E+00	31969.44	4.15	0	31969.44	4.15
25%	31969.44	0.00E+00	31969.44	4.15	0	31969.44	4.15
30%	31969.44	0.00E+00	31969.44	4.15	0	31969.44	4.15
35%	31969.44	0.00E+00	31969.44	4.15	0.0025	31969.44	4.15
40%	31969.44	0.00E+00	31969.44	4.15	0.0225	31969.46	4.15
45%	31969.44	0.00E+00	31969.44	4.15	0.09	31969.53	4.15
50%	31969.44	0.00E+00	31969.44	4.15	0.09	31969.53	4.15

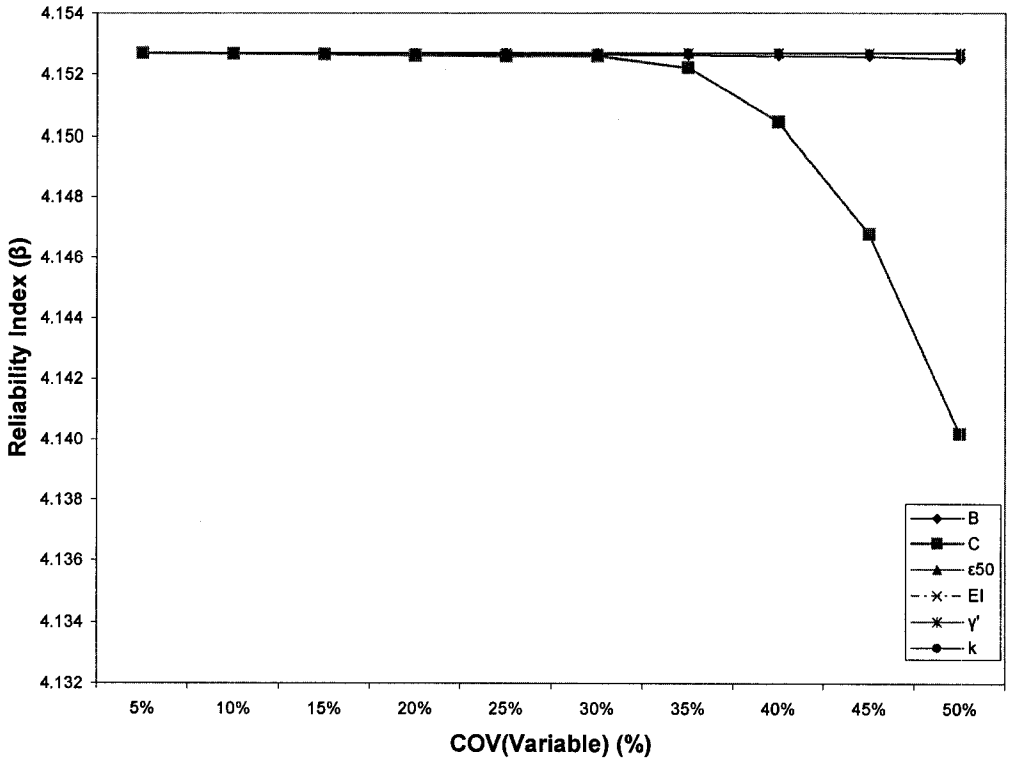

Fig. G.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (3D) at 953 kN lateral load.

For lateral load 1142 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 711.9 \text{ kN.m}$$

Table G.46 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'B' and 'C' and applied lateral load 1142 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.01	31969.45	3.98	0.04	31969.48	3.98
10%	31969.44	0.09	31969.53	3.98	0.1225	31969.56	3.98
15%	31969.44	0.2025	31969.64	3.98	0.3025	31969.74	3.98
20%	31969.44	0.3025	31969.74	3.98	0.49	31969.93	3.98
25%	31969.44	0.5625	31970.00	3.98	7.84	31977.28	3.98
30%	31969.44	1	31970.44	3.98	43.56	32013.00	3.98
35%	31969.44	1.3225	31970.76	3.98	113.4225	32082.86	3.97
40%	31969.44	1.8225	31971.26	3.98	251.2225	32220.66	3.97
45%	31969.44	76.5625	32046.00	3.98	470.89	32440.33	3.95
50%	31969.44	888.04	32857.48	3.93	829.44	32798.88	3.93

Table G.47 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying ε_{50} and EI and applied lateral load 1142 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.443	3.98	0.0020661	31969.442	3.98
10%	31969.44	0.01	31969.450	3.98	0.0082645	31969.448	3.98
15%	31969.44	0.0225	31969.463	3.98	0.0330579	31969.473	3.98
20%	31969.44	0.04	31969.480	3.98	0.0516529	31969.492	3.98
25%	31969.44	0.04	31969.480	3.98	0.0743802	31969.514	3.98
30%	31969.44	0.09	31969.530	3.98	0.0743802	31969.514	3.98
35%	31969.44	0.09	31969.530	3.98	0.1322314	31969.572	3.98
40%	31969.44	0.1225	31969.563	3.98	0.1673554	31969.607	3.98
45%	31969.44	0.25	31969.690	3.98	0.2066116	31969.647	3.98
50%	31969.44	0.4225	31969.863	3.98	0.2066116	31969.647	3.98

Table G.48 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'γ'' and 'k' and applied lateral load 1142 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
10%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
15%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
20%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
25%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
30%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
35%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
40%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
45%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98
50%	31969.44	0.00E+00	31969.44	3.98	0.00E+00	31969.44	3.98

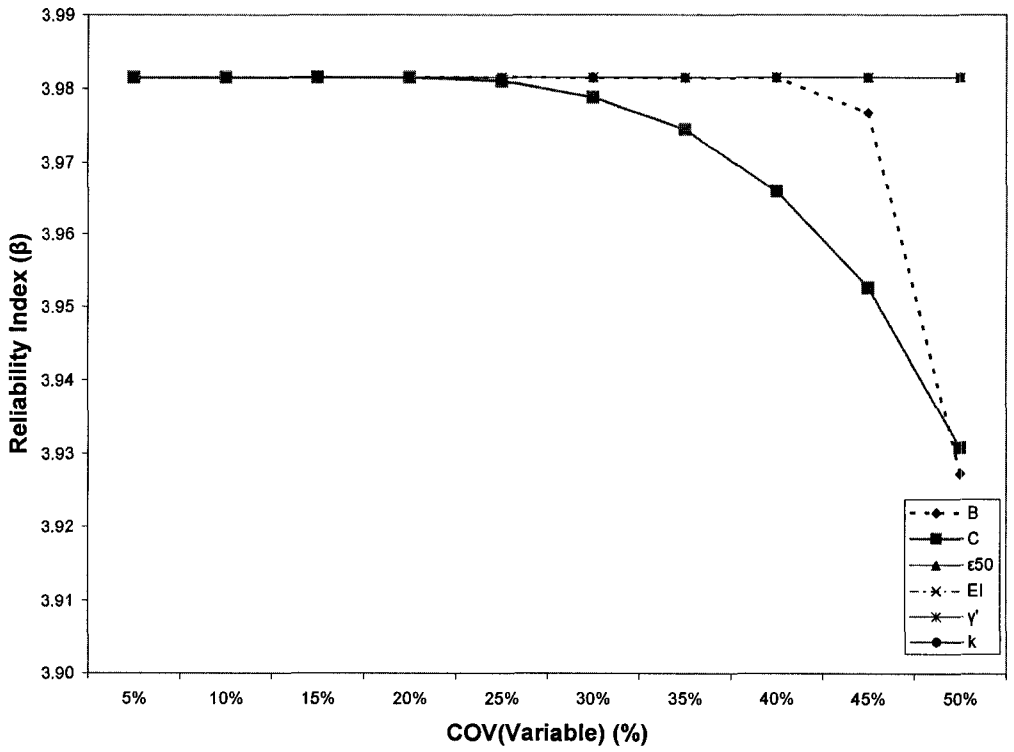

Fig. G.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (3D) at 1142 kN lateral load.

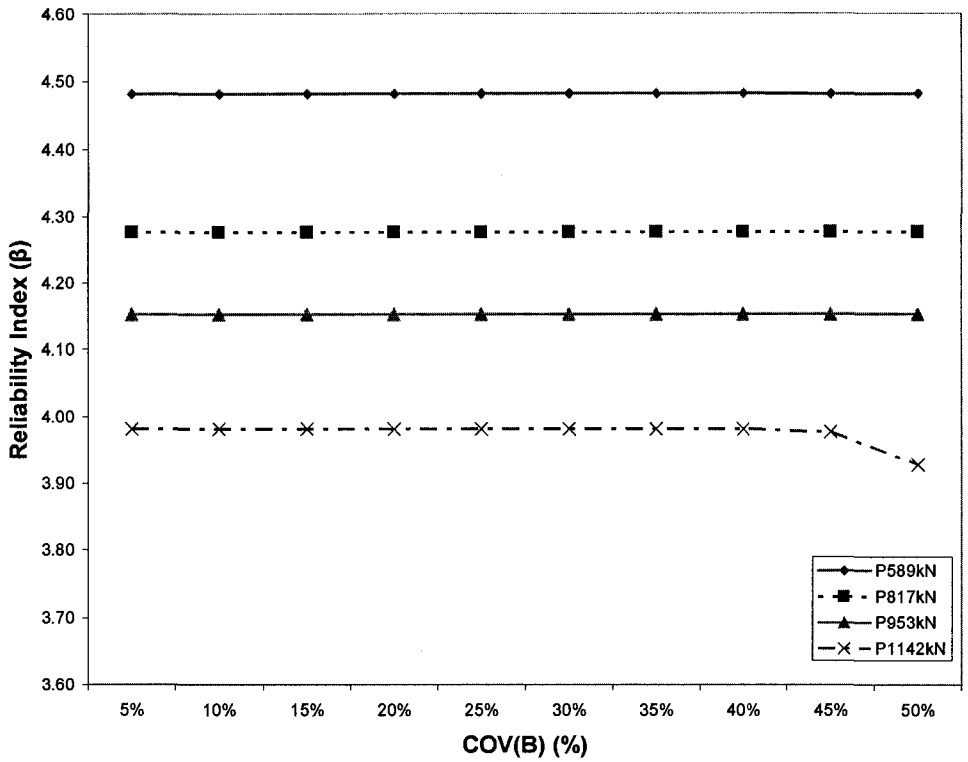

Fig. G.27 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'B'.

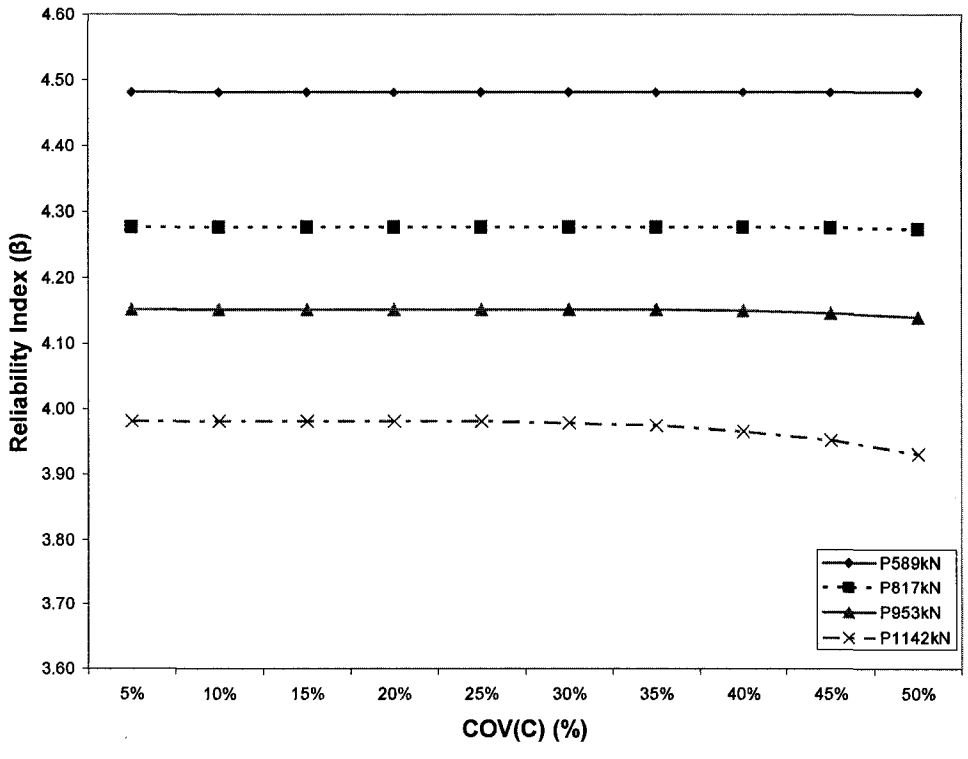

Fig. G.28 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'C'.

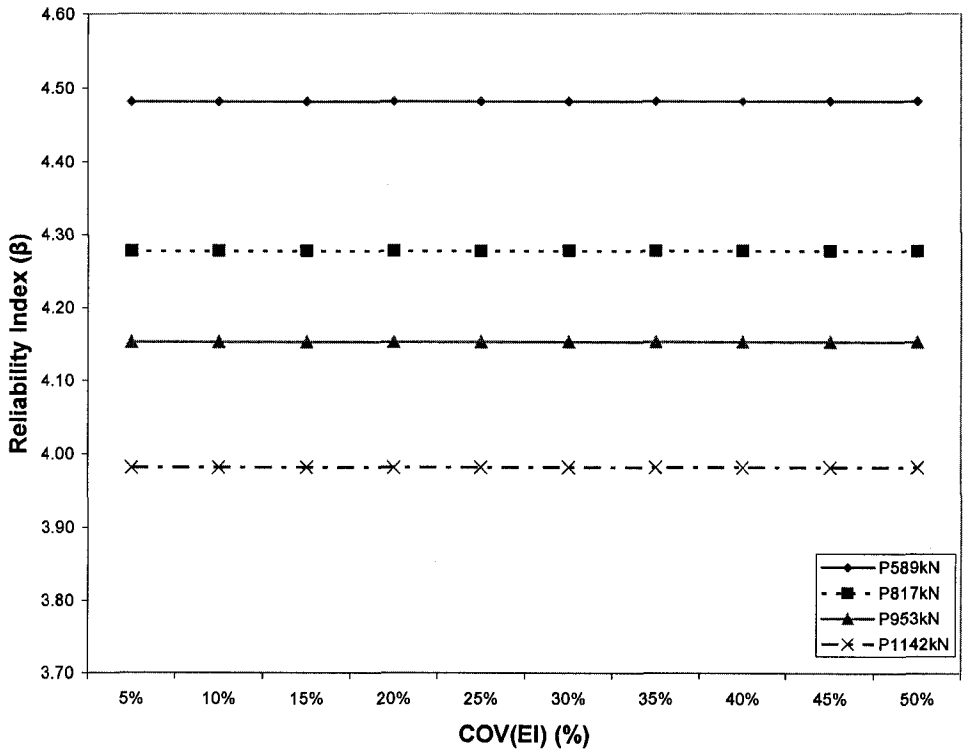

Fig. G.29 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'EI'.

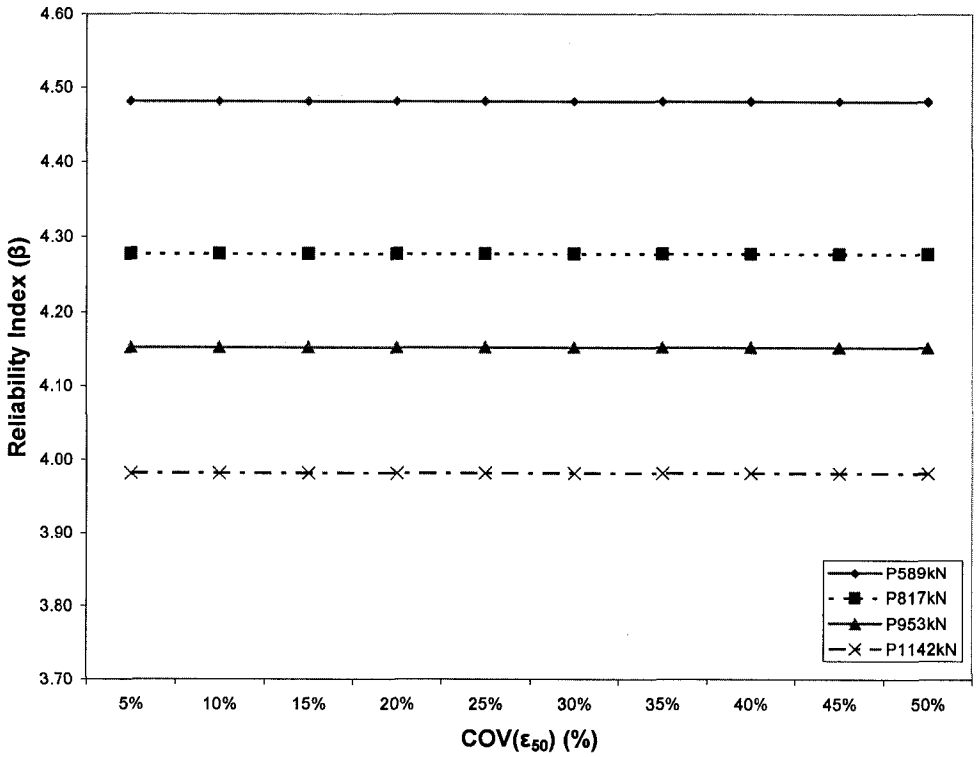

Fig. G.30 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'ε_{50}'.

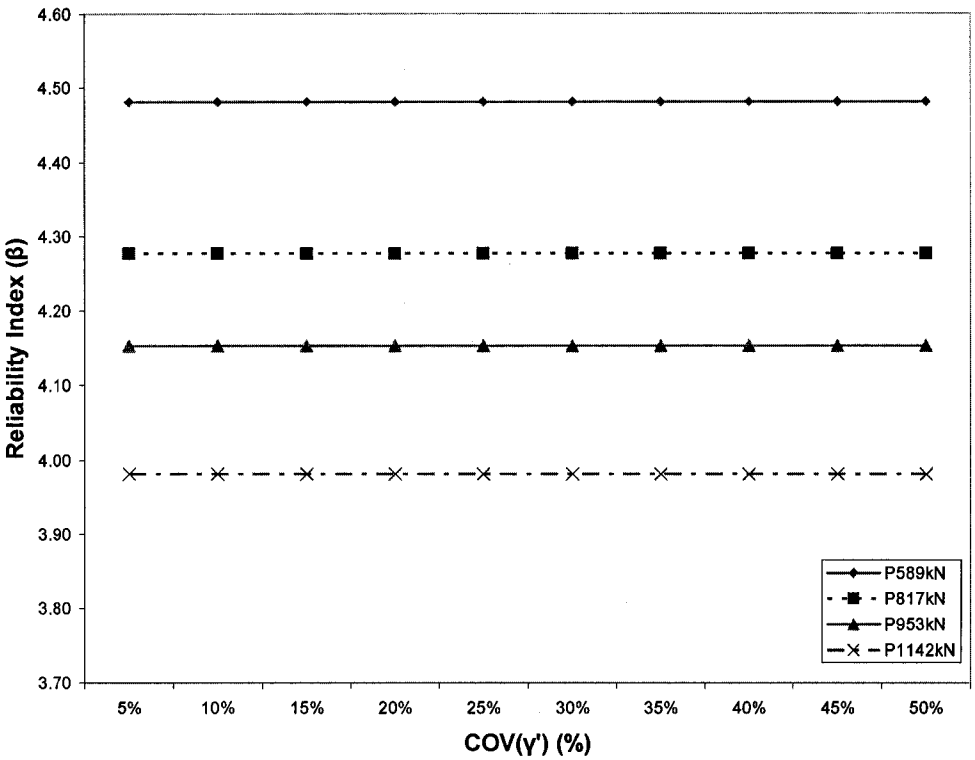

Fig. G.31 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'γ'.

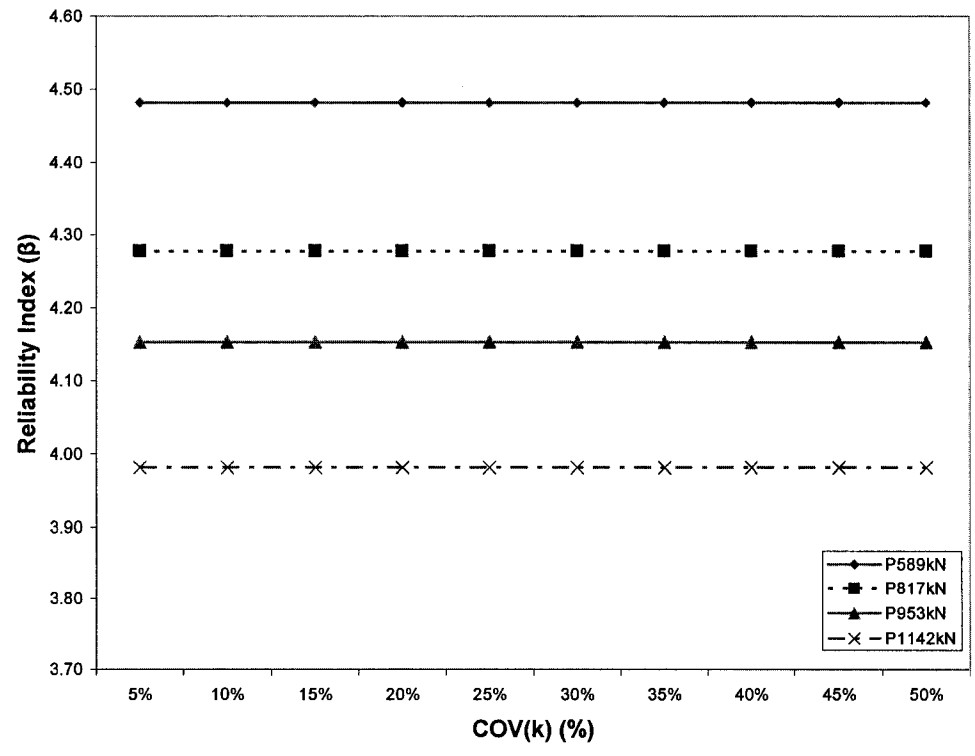

Fig. G.32 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (3D) and with varying 'k'.

APPENDIX H

LATERALLY LOADED FIXED HEAD LONG PILE

(Spacing: 3D)

H.1.1 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (3D) and with 'B' as varying random design variable

Table H.1. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 1477 kN and 1832 kN.

			P=1477 kN (150, 160, 190 kN)				P=1832 kN (180, 200, 230 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.0645	0.254	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45%	0.0523	0.2794	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
40%	0.0413	0.3048	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
35%	0.0316	0.3302	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
30%	0.0232	0.3556	0.00447	71.58	75.62	81	0.00676	98.33	105.6	114
25%	0.0161	0.381	0.00425	69.7	73.63	78.51	0.00631	94.68	101.6	109.5
20%	0.0103	0.4064	0.00408	68.33	72.18	76.93	0.00593	91.82	98.4	105.9
15%	0.0058	0.4318	0.00392	67.06	70.86	75.48	0.00566	89.71	96	103.2
10%	0.0026	0.4572	0.00379	66.07	69.81	74.33	0.00541	87.96	93.93	100.9
5%	0.0006	0.4826	0.00367	65.27	68.96	73.36	0.00521	86.64	92.3	99.11
0%	0.0000	0.508	0.00354	64.71	68.46	72.91	0.005	85.67	91.31	98.21
5%	0.0006	0.5334	0.00349	64.13	67.71	71.88	0.00492	84.8	90.12	96.71
10%	0.0026	0.5588	0.00342	63.69	67.22	71.49	0.00481	84.12	89.39	95.85
15%	0.0058	0.5842	0.00335	63.31	66.78	71.23	0.0047	83.44	88.64	94.98
20%	0.0103	0.6096	0.00329	62.99	66.39	71.07	0.00461	82.86	87.98	94.21
25%	0.0161	0.635	0.00324	62.83	66.19	70.73	0.00453	82.48	87.57	93.72
30%	0.0232	0.6604	0.00322	62.98	66.36	70.21	0.0045	82.51	87.62	93.8
35%	0.0316	0.6858	#	#	#	#	#	#	#	#
40%	0.0413	0.7112	#	#	#	#	#	#	#	#
45%	0.0523	0.7366	#	#	#	#	#	#	#	#
50%	0.0645	0.762	#	#	#	#	#	#	#	#

Table H.2 Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 2044 kN and 2283 kN.

			P=2044 kN (200, 220, 260 kN)				P=2283 kN (220, 250, 290 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.0645	0.254	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45%	0.0523	0.2794	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
40%	0.0413	0.3048	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
35%	0.0316	0.3302	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
30%	0.0232	0.3556	0.00864	116.9	126.6	138.6	0.012	141.8	156.1	174.6
25%	0.0161	0.381	0.0079	111.4	120.5	131.5	0.0103	132	144.7	160.2
20%	0.0103	0.4064	0.00738	107.4	116.1	126.3	0.00937	126.5	138	152
15%	0.0058	0.4318	0.00694	104.3	112.6	122.1	0.00867	122	132.7	145.7
10%	0.0026	0.4572	0.00659	101.9	109.8	118.8	0.00816	118.5	128.8	141
5%	0.0006	0.4826	0.0063	99.98	107.6	116.1	0.00777	116	125.9	137.5
0%	0.0000	0.508	0.00603	98.6	106.2	114.7	0.00737	114	123.8	135
5%	0.0006	0.5334	0.0059	97.48	104.6	112.6	0.00717	112.5	121.7	132.1
10%	0.0026	0.5588	0.00574	96.59	103.3	111.2	0.00694	111.2	120.1	130.1
15%	0.0058	0.5842	0.0056	95.83	102.3	110.1	0.00673	110	118.7	128.3
20%	0.0103	0.6096	0.00547	95.15	101.5	109.1	0.00657	109.2	117.6	127
25%	0.0161	0.635	0.00538	94.7	100.9	108.5	0.00644	108.6	116.8	126
30%	0.0232	0.6604	0.00534	94.69	100.9	108.5	0.00638	108.6	116.7	125.9
35%	0.0316	0.6858	#	#	#	#	#	#	#	#
40%	0.0413	0.7112	#	#	#	#	#	#	#	#
45%	0.0523	0.7366	#	#	#	#	#	#	#	#
50%	0.0645	0.762	#	#	#	#	#	#	#	#

Note: The digits in bracket beside the lateral load, shows the load distribution in rows of pile. For example, in **2044 kN** (200, 220, 260 kN), 2044 kN is an lateral load and 200, 220, and 260 kN are load distribution on pile rows A, B, C respectively.

Table H.3(a) Value of $COV(Y_{Top})$ for fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 1477 kN and 1832 kN.

		P=1477 kN		P=1832 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	8.10E-09	2.542%	2.10E-08	2.900%
10%	2.58E-03	3.42E-08	5.226%	9.00E-08	6.000%
15%	5.81E-03	8.12E-08	8.051%	2.30E-07	9.600%
20%	1.03E-02	1.56E-07	11.158%	4.36E-07	13.200%
25%	1.61E-02	2.55E-07	14.266%	7.92E-07	17.800%
30%	2.32E-02	3.91E-07	17.655%	1.28E-06	22.600%

Table H.3(b) Value of $COV(Y_{Top})$ for fixed head long pile (10T) pile group with spacing (3D) and with varying 'B' and lateral load 2044 kN and 2283 kN.

		P=2044 kN		P=2283 kN	
COV(B) (%)	Var (B) $(m)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	4.00E-08	3.317%	9.00E-08	4.071%
10%	2.58E-03	1.81E-07	7.048%	3.72E-07	8.277%
15%	5.81E-03	4.49E-07	11.111%	9.41E-07	13.161%
20%	1.03E-02	9.12E-07	15.837%	1.96E-06	18.996%
25%	1.61E-02	1.59E-06	20.896%	3.72E-06	26.187%
30%	2.32E-02	2.72E-06	27.363%	7.90E-06	38.128%

Table H.4(a) Value of $COV(M_{Max})$ for fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 1477 kN.

		P=1477 kN					
		VAR(M_{Max}) $(kN\text{-}m)^2$			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) $(m)^2$	A	B	C	A	B	C
5%	0.0006452	0.3249	0.390625	0.5476	0.88%	0.91%	1.01%
10%	0.0025806	1.4161	1.677025	2.0164	1.84%	1.89%	1.95%
15%	0.0058064	3.515625	4.1616	4.515625	2.90%	2.98%	2.91%
20%	0.0103226	7.1289	8.381025	8.5849	4.13%	4.23%	4.02%
25%	0.016129	11.799225	13.8384	6.05284	5.31%	5.43%	3.37%

Table H.4(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 1832 kN.

		P=1832 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.0006452	0.8464	1.1881	1.44	1.07%	1.19%	1.22%
10%	0.0025806	3.6864	5.1529	6.375625	2.24%	2.49%	2.57%
15%	0.0058064	9.828225	13.5424	16.8921	3.66%	4.03%	4.18%
20%	0.0103226	20.0704	27.1441	34.164025	5.23%	5.71%	5.95%
25%	0.016129	37.21	49.210225	62.2521	7.12%	7.68%	8.03%

Table H.4(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 2044 kN.

		P=2044 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.0006452	1.5625	2.25	3.0625	1.27%	1.41%	1.53%
10%	0.0025806	7.049025	10.5625	14.44	2.69%	3.06%	3.31%
15%	0.0058064	17.935225	26.5225	36	4.30%	4.85%	5.23%
20%	0.0103226	37.515625	53.29	73.96	6.21%	6.87%	7.50%
25%	0.016129	69.7225	96.04	132.25	8.47%	9.23%	10.03%

Table H.4(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'B' and lateral load 2283 kN.

		P=2283 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)^2	A	B	C	A	B	C
5%	0.0006452	3.0625	4.41	7.29	1.54%	1.70%	2.00%
10%	0.0025806	13.3225	18.9225	29.7025	3.20%	3.51%	4.04%
15%	0.0058064	36	49	75.69	5.26%	5.65%	6.44%
20%	0.0103226	74.8225	104.04	156.25	7.59%	8.24%	9.26%
25%	0.016129						

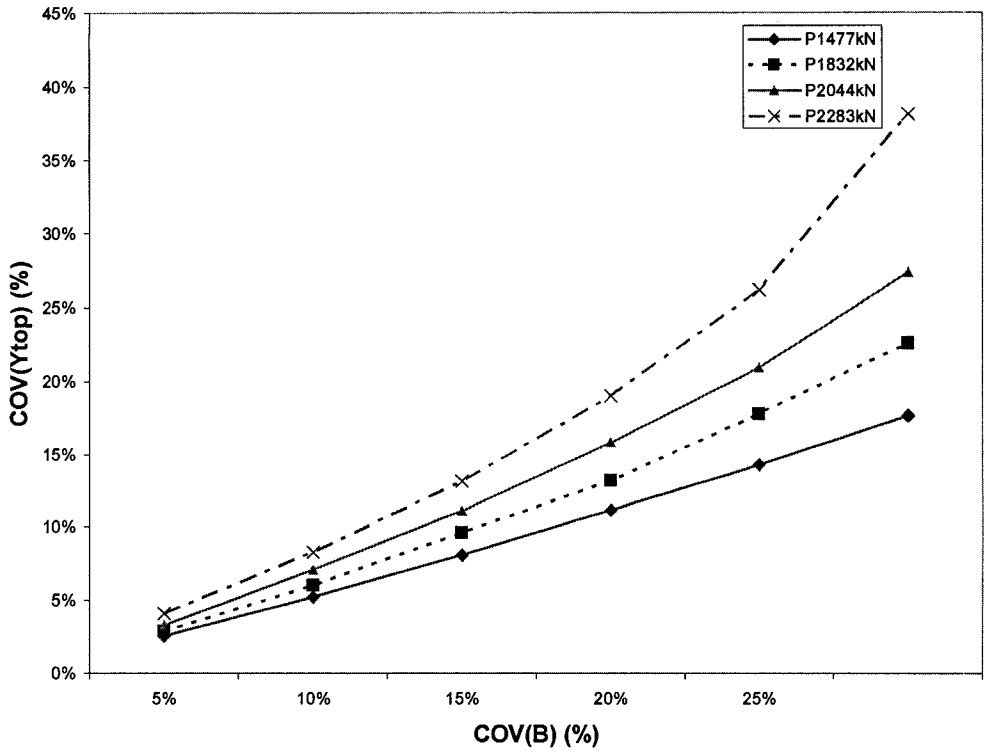

Fig. H.1 COV(Y_{Top}) for varying COV(B) in fixed head long (10T) pile group with spacing (3D).

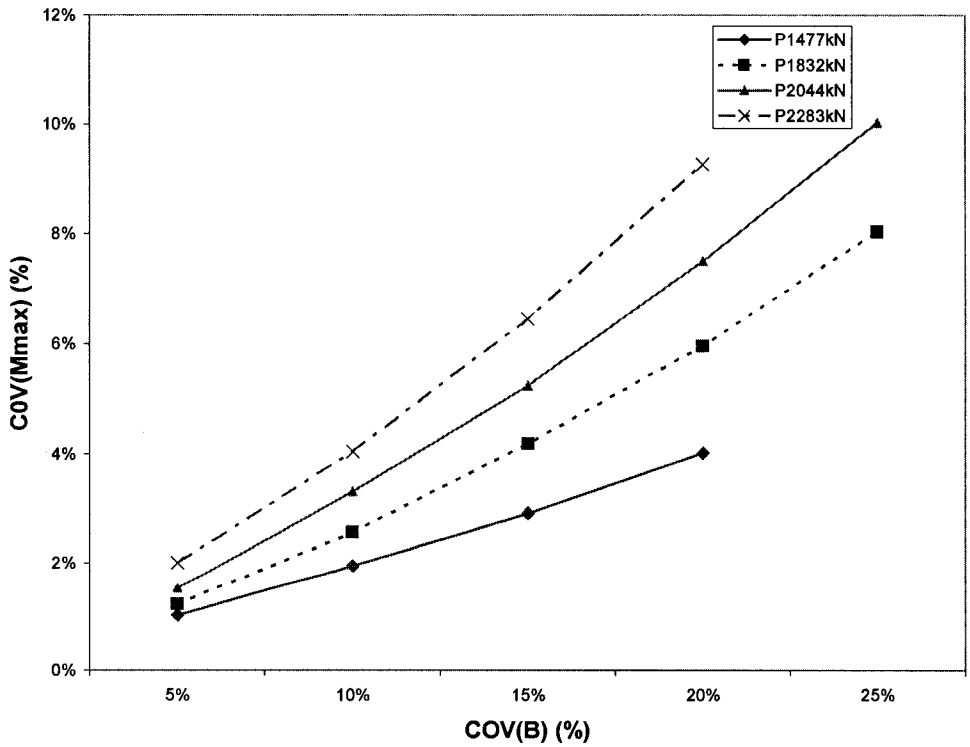

Fig. H.2(a) COV(M_{Max}) for varying COV(B) for pile C in fixed head long pile group with spacing (3D).

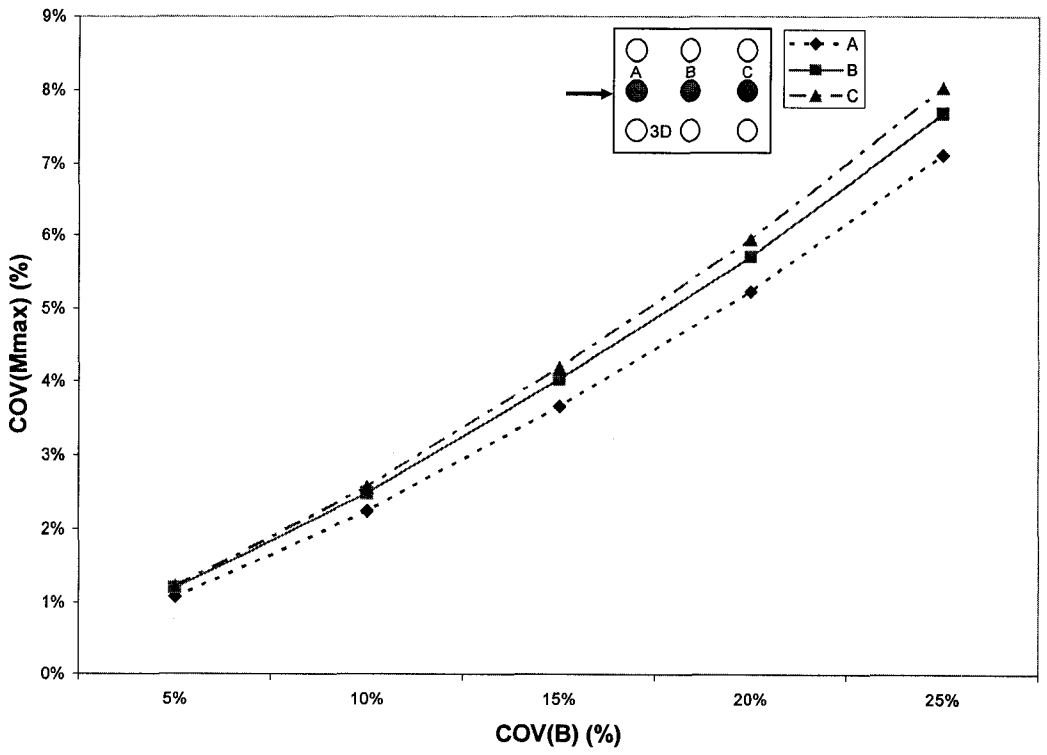

Fig. H.2(b) COV(M_{Max}) for varying COV(B) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (3D) at the optimum lateral load 1832 kN.

H.1.2 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (3D) with 'C' as varying random design variable

Table H.5. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 1477 kN and 1832 kN.

			P=1477 kN (150, 160, 190 kN)				P=1832 kN (180, 200, 230 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45.00%	1139.0625	41.25	0.0066	73.32	81.78	92.9	0.0102	103	110.1	121.3
40.00%	900	45	0.00599	73.06	81.03	91.22	0.00899	96.63	104.8	119.8
35.00%	689.0625	48.75	0.00546	72.52	79.89	89.08	0.00814	93.35	104	117.8
30.00%	506.25	52.5	0.00503	71.8	78.54	86.73	0.00743	92.71	102.7	115.4
25.00%	351.5625	56.25	0.00469	70.97	77.06	84.32	0.00684	91.89	101.2	112.8
20.00%	225	60	0.00439	69.97	75.51	81.82	0.00634	90.85	99.43	109.8
15.00%	126.5625	63.75	0.00415	68.86	73.85	79.59	0.00594	89.71	97.58	106.9
10.00%	56.25	67.5	0.00392	67.57	71.92	77.26	0.00558	88.43	95.6	103.8
5.00%	14.0625	71.25	0.00372	66.15	70.16	75.07	0.00527	87.09	93.52	100.8
0.00%	0	75	0.00354	64.71	68.46	72.91	0.005	85.67	91.31	98.21
5.00%	14.0625	78.75	0.00337	63.34	66.8	73.33	0.00478	84.14	89.38	95.79
10.00%	56.25	82.5	0.00323	62.01	65.14	73.91	0.00456	82.44	87.37	93.3
15.00%	126.5625	86.25	0.00309	60.7	64.16	74.36	0.00437	80.8	85.42	91.63
20.00%	225	90	0.00297	59.41	64.72	74.7	0.00419	79.22	83.49	92.35
25.00%	351.5625	93.75	0.00286	58.19	65.21	74.87	0.00402	77.64	81.52	92.93
30.00%	506.25	97.5	0.00277	58.48	65.65	74.9	0.00386	76.08	80.6	93.35
35.00%	689.0625	101.25	0.00269	58.86	65.84	74.96	0.00372	74.54	81.16	93.66
40.00%	900	105	0.00261	59.3	66.02	75.03	0.0036	73.07	81.65	93.8
45.00%	1139.0625	108.75	0.00254	59.59	66.17	75.11	0.00348	73.02	82.06	93.72
50.00%	1406.25	112.5	0.00247	59.77	66.31	75.15	0.00338	73.52	82.31	93.68

Table H.6. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 2044 kN and 2283 kN.

			P=2044 kN (200, 220, 260 kN)				P=2283 kN (220, 250, 290 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45.00%	1139.0625	41.25	0.0132	124.6	134.9	146.5	0.0193	155.9	172.3	193.3
40.00%	900	45	0.0115	117.1	125.1	137.5	0.0155	144.7	157.6	171.7
35.00%	689.0625	48.75	0.0102	109.9	118.7	136.2	0.0133	135.2	144.7	156.8
30.00%	506.25	52.5	0.00924	105.6	118.1	133.9	0.0118	126.6	134.9	155.2
25.00%	351.5625	56.25	0.00845	105.1	116.5	131	0.0106	119.6	134.2	153.1
20.00%	225	60	0.0078	104.1	114.8	128	0.00972	119.3	132.9	149.6
15.00%	126.5625	63.75	0.00725	102.9	112.8	124.8	0.00901	118.5	130.9	146.3
10.00%	56.25	67.5	0.00677	101.6	110.6	121.4	0.00838	117.1	128.6	142.6
5.00%	14.0625	71.25	0.00639	100.2	108.6	118.1	0.00784	115.6	126.2	139
0.00%	0	75	0.00603	98.6	106.2	114.7	0.00737	114	123.8	135
5.00%	14.0625	78.75	0.00572	97.01	103.7	111.7	0.00696	112.3	121.2	131.3
10.00%	56.25	82.5	0.00545	95.32	101.4	108.8	0.00663	110.5	118.7	128
15.00%	126.5625	86.25	0.00523	93.63	99.34	106.2	0.0063	108.7	115.9	124.6
20.00%	225	90	0.00501	91.82	97.2	103.5	0.00602	106.5	113.3	121.4
25.00%	351.5625	93.75	0.00481	103.5	90.06	95.08	0.00576	104.5	110.9	118.4
30.00%	506.25	97.5	0.00462	88.37	93	104.1	0.00554	102.7	108.6	116.2
35.00%	689.0625	101.25	0.00444	86.58	90.78	104.7	0.00533	100.8	106.3	117
40.00%	900	105	0.00428	84.91	90.87	105.1	0.00513	98.97	104	117.6
45.00%	1139.0625	108.75	0.00414	83.29	91.42	105.4	0.00496	97.15	101.8	118.1
50.00%	1406.25	112.5	0.00401	81.81	91.85	105.4	0.00479	95.36	102.5	118.4

Table H.7(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 1477 kN and 1832 kN.

		P=1477 kN		P=1832 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	14.0625	3.06E-08	4.944%	6.00E-08	4.900%
10.00%	56.25	1.19E-07	9.746%	2.60E-07	10.200%
15.00%	126.5625	2.81E-07	14.972%	6.16E-07	15.700%
20.00%	225	5.04E-07	20.056%	1.16E-06	21.500%
25.00%	351.5625	8.37E-07	25.847%	1.99E-06	28.200%
30.00%	506.25	1.28E-06	31.921%	3.19E-06	35.700%
35.00%	689.0625	1.92E-06	39.124%	4.88E-06	44.200%
40.00%	900	2.86E-06	47.740%	7.26E-06	53.900%
45.00%	1139.0625	4.12E-06	57.345%	1.13E-05	67.200%

Table H.7(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (3D) and with varying 'C' and lateral load 2044 kN and 2283 kN.

		P=2044 kN		P=2283 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	14.0625	1.12E-07	5.556%	1.94E-07	5.970%
10.00%	56.25	4.36E-07	10.945%	7.66E-07	11.872%
15.00%	126.5625	1.02E-06	16.750%	1.84E-06	18.385%
20.00%	225	1.95E-06	23.134%	3.42E-06	25.102%
25.00%	351.5625	3.31E-06	30.182%	5.86E-06	32.836%
30.00%	506.25	5.34E-06	38.308%	9.80E-06	42.469%
35.00%	689.0625	8.29E-06	47.761%	1.59E-05	54.071%
40.00%	900	1.30E-05	59.867%	2.69E-05	70.353%
45.00%	1139.0625	2.05E-05	75.124%	5.14E-05	97.286%

Table H.8(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 1477 kN.

		P=1477 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	1.974025	2.8224	0.7569	2.17%	2.45%	1.19%
10.00%	56.25	7.7284	11.4921	2.805625	4.30%	4.95%	2.30%
15.00%	126.5625	16.6464	23.474025	6.838225	6.31%	7.08%	3.59%
20.00%	225	27.8784	29.106025	12.6736	8.16%	7.88%	4.88%
25.00%	351.5625	40.8321	35.105625	8.93025	9.87%	8.65%	4.10%
30.00%	506.25	44.3556	41.538025	34.987225	10.29%	9.41%	8.11%
35.00%	689.0625	46.6489	49.350625	49.8436	10.55%	10.26%	9.68%
40.00%	900	47.3344	56.325025	65.529025	10.63%	10.96%	11.10%
45.00%	1139.0625	47.128225	60.918025	79.121025	10.61%	11.40%	12.20%

Table H.8(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 1832 kN.

		P=1832 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	2.175625	4.2849	6.275025	1.72%	2.27%	2.55%
10.00%	56.25	8.970025	16.933225	27.5625	3.50%	4.51%	5.35%
15.00%	126.5625	19.847025	36.9664	58.293225	5.20%	6.66%	7.77%
20.00%	225	33.814225	63.5209	76.125625	6.79%	8.73%	8.88%
25.00%	351.5625	50.765625	96.8256	98.704225	8.32%	10.78%	10.12%
30.00%	506.25	69.139225	122.1025	121.55063	9.71%	12.10%	11.23%
35.00%	689.0625	88.454025	130.4164	145.6849	10.98%	12.51%	12.29%
40.00%	900	138.7684	133.98063	169	13.75%	12.68%	13.24%
45.00%	1139.0625	224.7001	196.5604	190.1641	17.50%	15.35%	14.04%

Table H.8(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 2044 kN.

		P=2044 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	2.544025	6.0025	10.24	1.62%	2.31%	2.79%
10.00%	56.25	9.8596	21.16	39.69	3.18%	4.33%	5.49%
15.00%	126.5625	21.483225	45.2929	86.49	4.70%	6.34%	8.11%
20.00%	225	37.6996	77.44	150.0625	6.23%	8.29%	10.68%
25.00%	351.5625	0.64	174.7684	322.5616	0.81%	12.45%	15.66%
30.00%	506.25	74.218225	157.5025	222.01	8.74%	11.82%	12.99%
35.00%	689.0625	135.9556	194.8816	248.0625	11.83%	13.15%	13.73%
40.00%	900	259.04903	292.92323	262.44	16.32%	16.12%	14.12%
45.00%	1139.0625	426.62903	472.6276	422.3025	20.95%	20.47%	17.92%

Table H.8(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'C' and lateral load 2283 kN.

		P=2283 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	2.7225	6.25	14.8225	1.45%	2.02%	2.85%
10.00%	56.25	10.89	24.5025	53.29	2.89%	4.00%	5.41%
15.00%	126.5625	24.01	56.25	117.7225	4.30%	6.06%	8.04%
20.00%	225	40.96	96.04	198.81	5.61%	7.92%	10.44%
25.00%	351.5625	57.0025	135.7225	301.0225	6.62%	9.41%	12.85%
30.00%	506.25	142.8025	172.9225	380.25	10.48%	10.62%	14.44%
35.00%	689.0625	295.84	368.64	396.01	15.09%	15.51%	14.74%
40.00%	900	522.80823	718.24	731.7025	20.06%	21.65%	20.04%
45.00%	1139.0625	862.89063	1242.5625	1413.76	25.77%	28.47%	27.85%

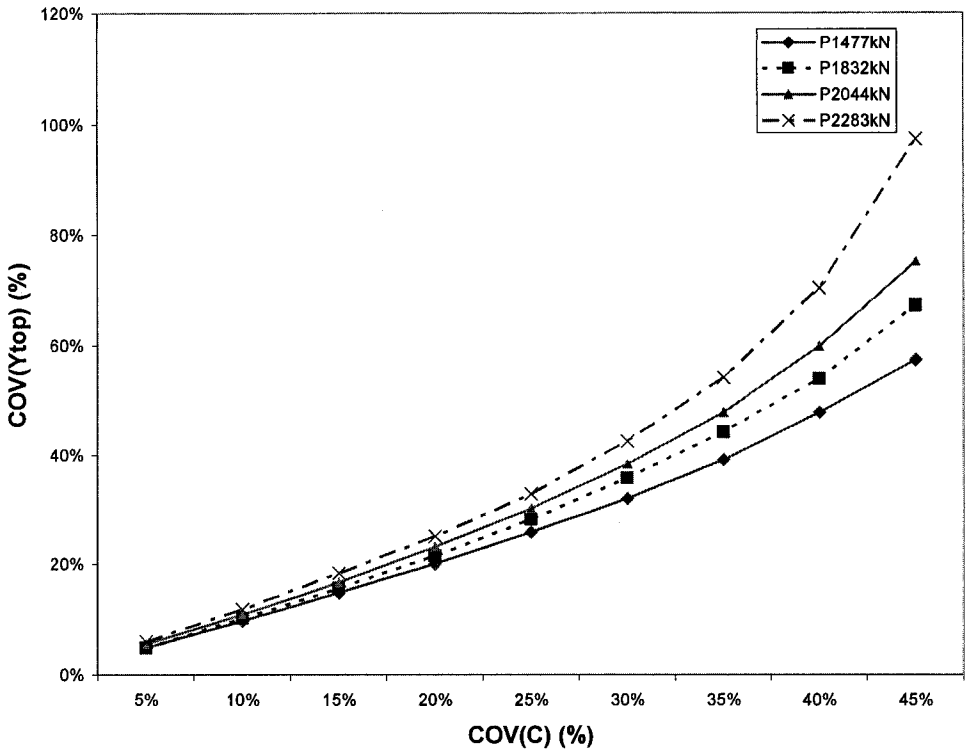

Fig. H.3 COV(Y_{Top}) for varying COV(C) in fixed head long (10T) pile group with spacing (3D).

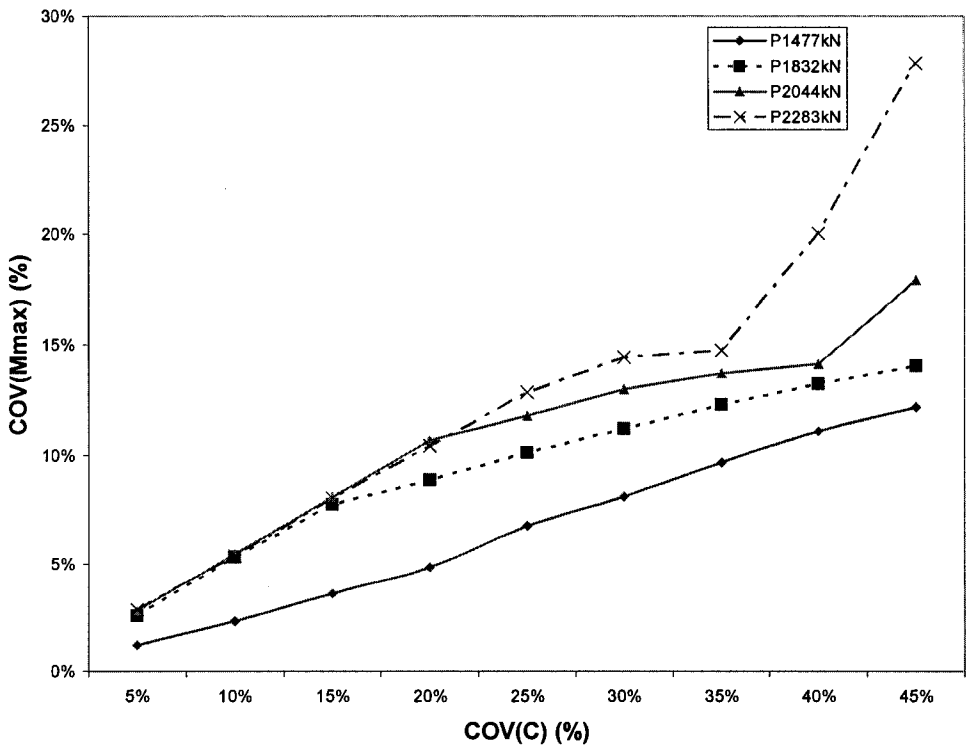

Fig. H.4(a) COV(M_{Max}) for varying COV(C) for pile C in fixed head long pile group with spacing (3D).

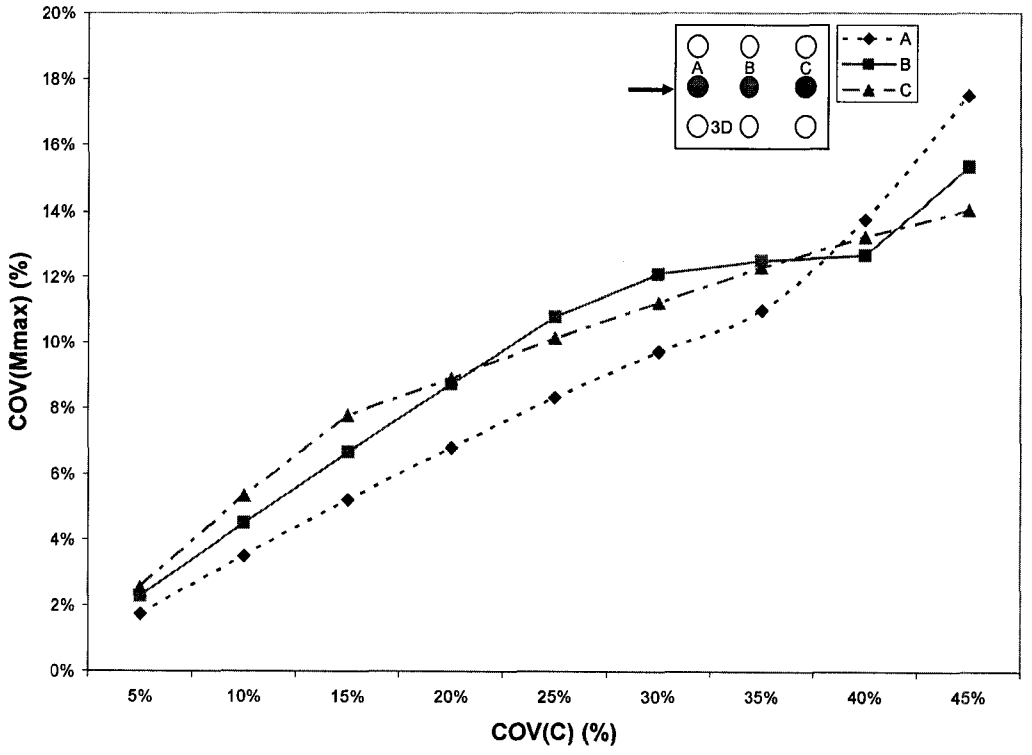

Fig. H.4(b) COV(M_{Max}) for varying COV(C) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (3D) at the optimum lateral load 1832 kN.

H.1.3 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (3D) and with 'ε_{50}' as varying random design variable

Table H.9. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 1477 kN and 1832 kN.

			P=1477 kN (150, 160, 190 kN)				P=1832 kN (180, 200, 230 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00273	60.71	67.83	77.19	0.00392	79.29	84.58	98.34
45%	9.9225E-06	0.00385	0.00282	59.92	67.27	76.82	0.00404	80.14	84.04	97.25
40%	0.00000784	0.0042	0.00291	59.53	66.63	76.52	0.00416	80.95	85.13	96.11
35%	6.0025E-06	0.00455	0.00298	60.3	66.04	76.16	0.00429	81.81	86.3	95.05
30%	0.00000441	0.0049	0.00307	61.18	65.36	75.64	0.0044	82.47	87.18	94
25%	3.0625E-06	0.00525	0.00316	61.9	64.83	75.14	0.0045	83.06	87.95	93.65
20%	0.00000196	0.0056	0.00324	62.56	65.69	74.64	0.0046	83.66	88.71	94.72
15%	1.1025E-06	0.00595	0.00331	63.16	66.48	74.13	0.00471	84.23	89.41	95.69
10%	0.00000049	0.0063	0.00339	63.71	67.2	73.62	0.0048	84.79	90.08	96.59
5%	1.225E-07	0.00665	0.00346	64.23	67.86	73.11	0.0049	85.3	90.71	97.43
0%	0	0.007	0.00354	64.73	68.47	72.92	0.005	85.69	91.32	98.23
5%	1.225E-07	0.00735	0.0036	65.19	69.05	73.71	0.00509	86.02	91.91	98.98
10%	0.00000049	0.0077	0.00367	65.64	69.59	74.42	0.00518	86.3	92.48	99.68
15%	1.1025E-06	0.00805	0.00374	66.06	70.11	75.09	0.00529	86.59	93.11	100.5
20%	0.00000196	0.0084	0.00382	66.51	70.72	75.84	0.00536	86.77	93.45	101
25%	3.0625E-06	0.00875	0.00387	66.81	71.07	76.32	0.00545	86.97	92.83	101.6
30%	0.00000441	0.0091	0.00393	67.1	71.52	76.89	0.00555	87.16	94.22	102.4
35%	6.0025E-06	0.00945	0.00399	67.37	71.97	77.45	0.00563	87.3	94.52	103
40%	0.00000784	0.0098	0.00406	67.63	72.41	77.99	0.00572	87.42	94.8	103.5
45%	9.9225E-06	0.01015	0.00412	67.85	72.81	78.49	0.0058	87.53	95.06	104
50%	0.00001225	0.0105	0.00418	68.06	73.17	78.99	0.00586	87.61	95.25	104.4

Table H.10. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 2044 kN and 2283 kN.

			P=2044 kN (200, 220, 260 kN)				P=2283 kN (220, 250, 290 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00484	94.45	99.55	109.4	0.00613	113.8	121	129.5
45%	9.9225E-06	0.00385	0.00497	94.9	100.3	108	0.00624	113.6	120.9	129.7
40%	0.00000784	0.0042	0.00509	95.37	101	107.6	0.00636	113.6	121.1	130.2
35%	6.0025E-06	0.00455	0.00523	96.02	101.9	108.9	0.0065	113.9	121.5	130.9
30%	0.00000441	0.0049	0.00535	96.49	102.6	109.9	0.00662	114	121.8	131.4
25%	3.0625E-06	0.00525	0.00546	96.97	103.2	110.7	0.00674	114	122.2	131.9
20%	0.00000196	0.0056	0.00557	97.47	103.8	111.6	0.00689	114.1	122.9	132.8
15%	1.1025E-06	0.00595	0.00569	97.84	104.4	112.4	0.00701	114.1	123.2	133.3
10%	0.00000049	0.0063	0.00582	98.23	105.2	113.4	0.00713	114.1	123.4	133.9
5%	1.225E-07	0.00665	0.00592	98.45	105.8	114.1	0.00725	114	123.6	134.5
0%	0	0.007	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135.1
5%	1.225E-07	0.00735	0.00613	98.79	106.6	115.4	0.00748	114	124	135.7
10%	0.00000049	0.0077	0.00623	98.94	107	116.1	0.0076	113.9	124.1	136.2
15%	1.1025E-06	0.00805	0.00633	99.08	107.3	116.7	0.00771	113.9	124.2	136.7
20%	0.00000196	0.0084	0.00643	99.19	107.6	117.3	0.00783	113.8	124.4	137.1
25%	3.0625E-06	0.00875	0.00653	99.28	107.9	117.9	0.00794	113.7	124.5	137.5
30%	0.00000441	0.0091	0.00663	99.36	108.1	118.5	0.00805	113.7	124.6	137.8
35%	6.0025E-06	0.00945	0.00673	99.43	108	119	0.00819	113.6	124.7	138.3
40%	0.00000784	0.0098	0.00682	99.48	108.6	119.4	0.00829	113.5	124.8	138.6
45%	9.9225E-06	0.01015	0.00692	99.52	108.7	119.8	0.0084	113.4	124.8	138.8
50%	0.00001225	0.0105	0.00701	99.54	108.9	120.2	0.0085	113.3	124.8	139.1

Table H.11(a) Value of $COV(Y_{Top})$ for fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 1477 kN and 1832 kN.

		P=1477 kN		P=1832 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	4.90E-09	1.977%	9.02E-09	1.900%
10%	4.90E-07	1.96E-08	3.955%	3.61E-08	3.800%
15%	1.10E-06	4.62E-08	6.073%	8.41E-08	5.800%
20%	1.96E-06	8.41E-08	8.192%	1.44E-07	7.600%
25%	3.06E-06	1.26E-07	10.028%	2.26E-07	9.500%
30%	4.41E-06	1.85E-07	12.147%	3.31E-07	11.500%
35%	6.00E-06	2.55E-07	14.266%	4.49E-07	13.400%
40%	7.84E-06	3.31E-07	16.243%	6.08E-07	15.600%
45%	9.92E-06	4.23E-07	18.362%	7.74E-07	17.600%
50%	1.23E-05	5.26E-07	20.480%	9.41E-07	19.400%

Table H.11(b) Value of $COV(Y_{Top})$ for fixed head long pile (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 2044 kN and 2283 kN.

		P=2044 kN		P=2283 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	1.10E-08	1.741%	1.32E-08	1.560%
10%	4.90E-07	4.20E-08	3.400%	5.52E-08	3.189%
15%	1.10E-06	1.02E-07	5.307%	1.23E-07	4.749%
20%	1.96E-06	1.85E-07	7.131%	2.21E-07	6.377%
25%	3.06E-06	2.86E-07	8.872%	3.60E-07	8.141%
30%	4.41E-06	4.10E-07	10.614%	5.11E-07	9.701%
35%	6.00E-06	5.63E-07	12.438%	7.14E-07	11.465%
40%	7.84E-06	7.48E-07	14.345%	9.31E-07	13.094%
45%	9.92E-06	9.51E-07	16.169%	1.17E-06	14.654%
50%	1.23E-05	1.18E-06	17.993%	1.40E-06	16.079%

Table H.12(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 1477 kN.

		P=1477 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.2304	0.354025	0.09	0.74%	0.87%	0.41%
10%	4.90E-07	0.931225	1.428025	0.16	1.49%	1.75%	0.55%
15%	1.10E-06	2.1025	3.294225	0.2304	2.24%	2.65%	0.66%
20%	1.96E-06	3.900625	6.325225	0.36	3.05%	3.67%	0.82%
25%	3.06E-06	6.027025	9.7344	0.13924	3.79%	4.56%	0.51%
30%	4.41E-06	8.7616	9.4864	0.390625	4.57%	4.50%	0.86%
35%	6.00E-06	12.496225	8.791225	0.416025	5.46%	4.33%	0.88%
40%	7.84E-06	16.4025	8.3521	0.540225	6.26%	4.22%	1.01%
45%	9.92E-06	15.721225	7.6729	0.697225	6.13%	4.05%	1.15%
50%	1.23E-05	13.505625	7.1289	0.81	5.68%	3.90%	1.23%

Table H.12(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 1832 kN.

		P=1832 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.1296	0.36	0.600625	0.42%	0.66%	0.79%
10%	4.90E-07	0.570025	1.44	2.387025	0.88%	1.31%	1.57%
15%	1.10E-06	1.3924	3.4225	5.784025	1.38%	2.03%	2.45%
20%	1.96E-06	2.418025	5.6169	9.8596	1.81%	2.60%	3.20%
25%	3.06E-06	3.822025	5.9536	15.800625	2.28%	2.67%	4.05%
30%	4.41E-06	5.499025	12.3904	17.64	2.74%	3.85%	4.28%
35%	6.00E-06	7.535025	16.8921	15.800625	3.20%	4.50%	4.05%
40%	7.84E-06	10.465225	23.377225	13.653025	3.78%	5.29%	3.76%
45%	9.92E-06	13.653025	30.3601	11.390625	4.31%	6.03%	3.44%
50%	1.23E-05	17.3056	28.462225	9.1809	4.85%	5.84%	3.08%

Table H.12(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 2044 kN.

		P=2044 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0289	0.16	0.4225	0.17%	0.38%	0.57%
10%	4.90E-07	0.126025	0.81	1.8225	0.36%	0.85%	1.18%
15%	1.10E-06	0.3844	2.1025	4.6225	0.63%	1.37%	1.87%
20%	1.96E-06	0.7396	3.61	8.1225	0.87%	1.79%	2.48%
25%	3.06E-06	1.334025	5.5225	12.96	1.17%	2.21%	3.14%
30%	4.41E-06	2.059225	7.5625	18.49	1.46%	2.59%	3.75%
35%	6.00E-06	2.907025	9.3025	25.5025	1.73%	2.87%	4.40%
40%	7.84E-06	4.223025	14.44	34.81	2.08%	3.58%	5.14%
45%	9.92E-06	5.3361	17.64	34.81	2.34%	3.95%	5.14%
50%	1.23E-05	6.477025	21.855625	29.16	2.58%	4.40%	4.71%

Table H.12(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'ε_{50}' and lateral load 2283 kN.

		P=2283 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0	0.04	0.36	0.00%	0.16%	0.44%
10%	4.90E-07	0.01	0.1225	1.3225	0.09%	0.28%	0.85%
15%	1.10E-06	0.01	0.25	2.89	0.09%	0.40%	1.26%
20%	1.96E-06	0.0225	0.5625	4.6225	0.13%	0.61%	1.59%
25%	3.06E-06	0.0225	1.3225	7.84	0.13%	0.93%	2.07%
30%	4.41E-06	0.0225	1.96	10.24	0.13%	1.13%	2.37%
35%	6.00E-06	0.0225	2.56	13.69	0.13%	1.29%	2.74%
40%	7.84E-06	0.0025	3.4225	17.64	0.04%	1.49%	3.11%
45%	9.92E-06	0.01	3.8025	20.7025	0.09%	1.58%	3.37%
50%	1.23E-05	0.0625	3.61	23.04	0.22%	1.53%	3.55%

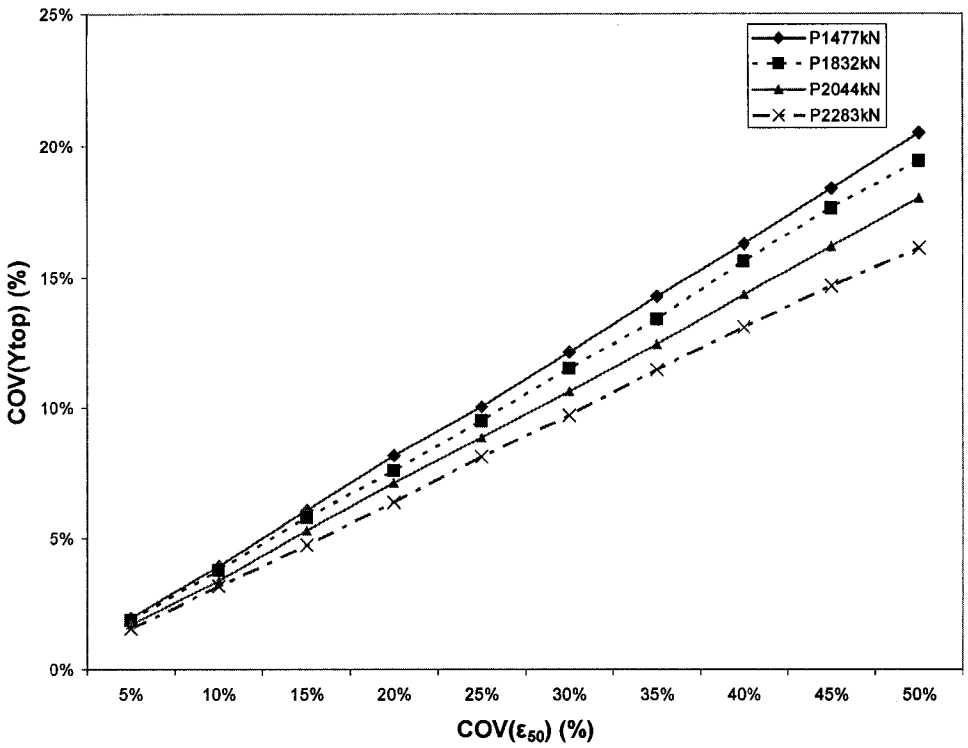

Fig. H.5 COV(Y_{Top}) for varying COV(ε_{50}) in fixed head long (10T) pile group with spacing (3D).

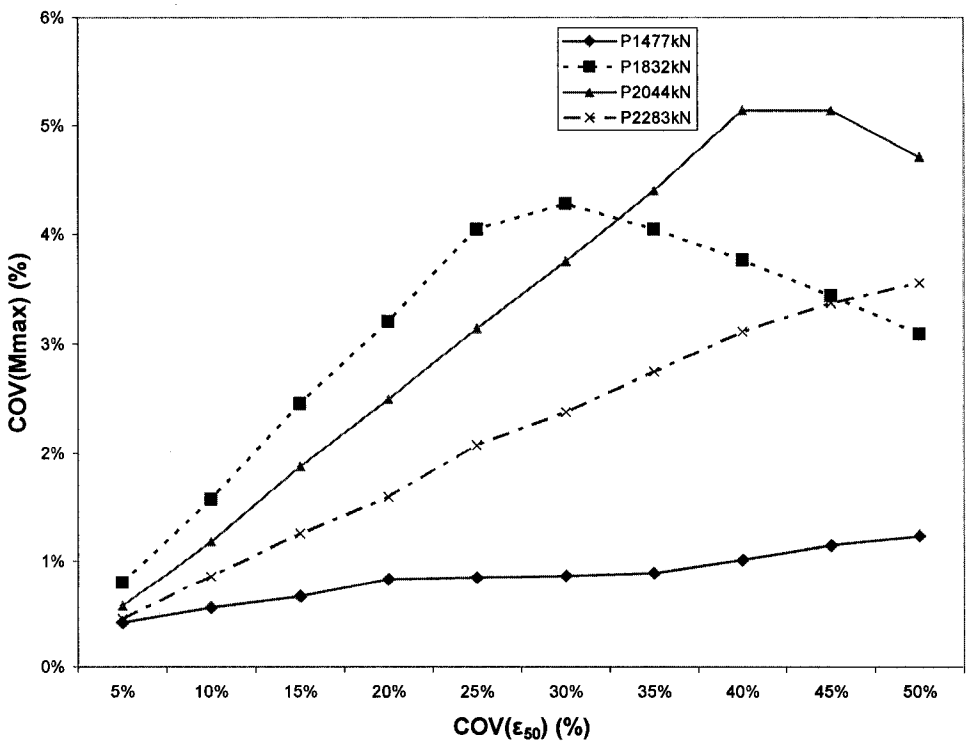

Fig. H.6(a) COV(M_{Max}) for varying COV(ε_{50}) for pile C in fixed head long pile group with spacing (3D).

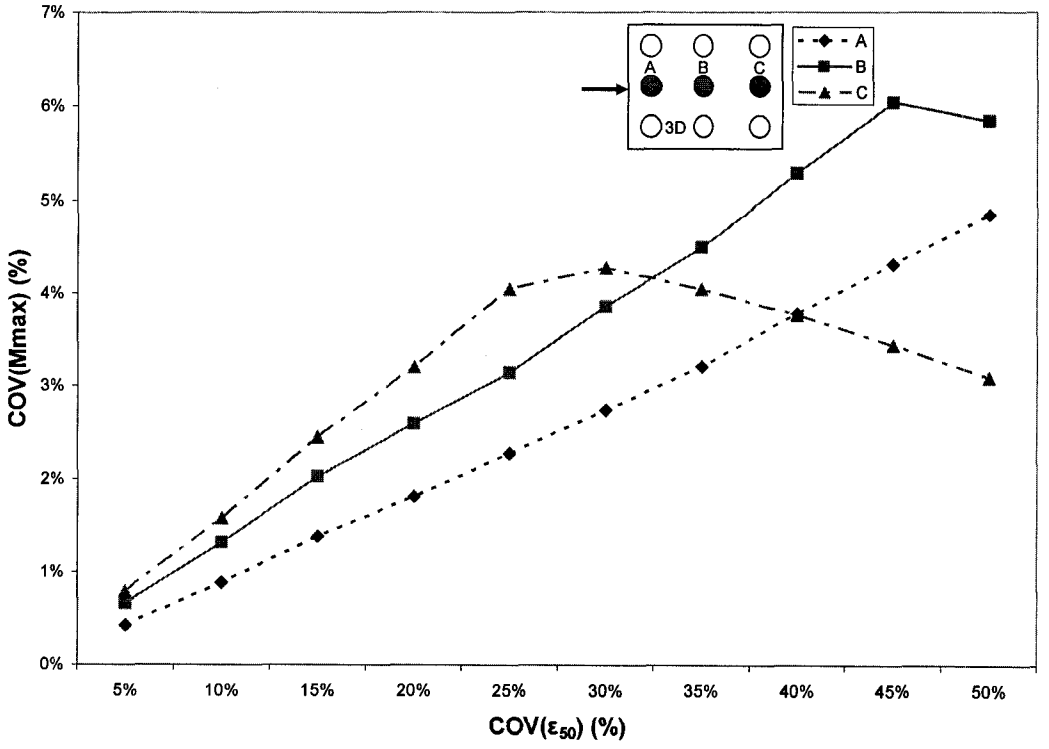

Fig. H.6(b) COV(M_{Max}) for varying COV(ε_{50}) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (3D) at the optimum lateral load 1832 kN.

H.1.4 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (3D) and with 'EI' as varying random design variable

Table H.13. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 1477 kN and 1832 kN.

			P=1477 kN (150, 160, 190 kN)				P=1832 kN (180, 200, 230 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(kN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	2.50E+09	55000	0.00499	55.22	62.32	71.51	0.0072	74.16	77.79	90.05
45%	2.03E+09	60500	0.00475	55.37	62.24	71.64	0.00685	75.75	79.62	89.8
40%	1.60E+09	66000	0.00455	56.68	62.17	71.75	0.00654	77.06	81.18	89.51
35%	1.23E+09	71500	0.00437	57.89	62.1	71.86	0.00626	78.32	82.64	89.26
30%	9.00E+08	77000	0.00423	59.11	62.01	71.93	0.00603	79.52	84.04	89.19
25%	6.25E+08	82500	0.00409	60.16	63.07	72.02	0.00582	80.64	85.33	90.78
20%	4.00E+08	88000	0.00397	61.16	64.25	72.1	0.00563	81.74	86.58	92.32
15%	2.25E+08	93500	0.00386	62.1	65.35	72.18	0.00549	82.99	88	94.02
10%	1.00E+08	99000	0.00375	62.96	66.34	72.24	0.00534	83.94	89.1	95.35
5%	2.50E+07	104500	0.00366	63.81	67.33	72.29	0.00518	84.76	90.02	96.51
0%	0.00E+00	110000	0.00354	64.71	68.46	72.91	0.005	85.67	91.31	98.21
5%	2.50E+07	115500	0.0035	65.44	69.19	73.68	0.00494	86.44	92.12	99.02
10%	1.00E+08	121000	0.00343	66.21	70.07	74.76	0.00484	87.23	93.12	100.2
15%	2.25E+08	126500	0.00336	66.96	70.92	75.79	0.00474	87.97	94.1	101.4
20%	4.00E+08	132000	0.0033	67.68	71.74	76.77	0.00466	88.73	95.2	102.6
25%	6.25E+08	137500	0.00324	68.39	72.54	77.72	0.00458	89.42	96.07	103.7
30%	9.00E+08	143000	0.00319	69.07	73.31	78.64	0.00448	90.04	96.82	104.6
35%	1.23E+09	148500	0.00316	69.37	73.66	79.05	0.00444	90.32	97.17	105.1
40%	1.60E+09	154000	0.00309	70.37	74.79	80.39	0.00434	91.3	98.39	106.6
45%	2.03E+09	159500	0.00305	70.97	75.5	81.24	0.00428	91.91	99.14	107.6
50%	2.50E+09	165000	0.00301	71.54	76.2	82.06	0.00421	92.5	99.88	108.5

Table H.14. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 2044 kN and 2283 kN.

			P=2044 kN (200, 220, 260 kN)				P=2283 kN (220, 250, 290 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(kN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	2.50E+09	55000	0.00888	88.21	93.13	100.1	0.0112	106.1	112.7	120.3
45%	2.03E+09	60500	0.00839	89.47	94.64	100.5	0.0105	106.9	113.8	121.7
40%	1.60E+09	66000	0.00798	90.69	96.09	102.3	0.00996	107.9	115.1	123.4
35%	1.23E+09	71500	0.00763	91.88	97.47	104	0.00948	108.8	116.3	124.9
30%	9.00E+08	77000	0.00735	93.24	98.99	105.8	0.00907	109.6	117.5	126.3
25%	6.25E+08	82500	0.00705	94.12	100	107.2	0.00871	110.4	118.6	127.7
20%	4.00E+08	88000	0.00681	95.1	101.3	108.7	0.0084	111.1	119.7	129.1
15%	2.25E+08	93500	0.00662	96.12	102.7	110.3	0.00812	111.9	120.7	130.5
10%	1.00E+08	99000	0.00643	96.99	103.8	111.7	0.00787	112.6	121.7	131.9
5%	2.50E+07	104500	0.00625	97.83	104.9	113	0.00765	113.3	122.6	133.2
0%	0.00E+00	110000	0.00603	98.6	106.2	114.7	0.00737	114	123.8	135
5%	2.50E+07	115500	0.00595	99.37	106.9	115.5	0.00726	114.7	124.4	135.8
10%	1.00E+08	121000	0.00582	100.1	107.9	116.8	0.00709	115.4	125.3	137.1
15%	2.25E+08	126500	0.00569	100.8	108.8	117.9	0.00693	116	126.1	138.3
20%	4.00E+08	132000	0.00558	101.5	109.7	119.1	0.00678	116.6	126.9	139.4
25%	6.25E+08	137500	0.00547	102	110.5	120.2	0.00665	117.3	127.7	140.5
30%	9.00E+08	143000	0.00538	102.9	111.4	121.4	0.00653	117.9	128.5	141.5
35%	1.23E+09	148500	0.00533	103.1	111.7	121.9	0.00646	118.1	128.8	142
40%	1.60E+09	154000	0.0052	104.1	112.9	123.5	0.0063	119.1	130	143.6
45%	2.03E+09	159500	0.00512	104.7	113.7	124.6	0.0062	119.7	130.7	144.5
50%	2.50E+09	165000	0.00504	105.3	114.4	125.5	0.0061	120.2	131.4	145.5

Table H.15(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 1477 kN and 1832 kN.

		P=1477 kN		P=1832 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	2.50E+07	5.29E-09	2.054%	1.19E-08	2.182%
10%	1.00E+08	2.12E-08	4.109%	5.17E-08	4.545%
15%	2.25E+08	5.17E-08	6.420%	1.16E-07	6.818%
20%	4.00E+08	9.27E-08	8.603%	1.94E-07	8.818%
25%	6.25E+08	1.49E-07	10.914%	3.18E-07	11.273%
30%	9.00E+08	2.23E-07	13.354%	4.96E-07	14.091%
35%	1.23E+09	3.03E-07	15.537%	6.84E-07	16.545%
40%	1.60E+09	4.40E-07	18.747%	1.00E-06	20.000%
45%	2.03E+09	5.97E-07	21.828%	1.36E-06	23.364%
50%	2.50E+09	8.10E-07	25.424%	1.85E-06	27.182%

Table H.15(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 2044 kN and 2283 kN.

		P=2044 kN		P=2283 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	2.50E+07	1.86E-08	2.261%	3.14E-08	2.405%
10%	1.00E+08	7.69E-08	4.598%	1.26E-07	4.811%
15%	2.25E+08	1.79E-07	7.010%	2.93E-07	7.339%
20%	4.00E+08	3.13E-07	9.272%	5.42E-07	9.991%
25%	6.25E+08	5.16E-07	11.910%	8.77E-07	12.705%
30%	9.00E+08	8.02E-07	14.850%	1.33E-06	15.665%
35%	1.23E+09	1.09E-06	17.338%	1.88E-06	18.626%
40%	1.60E+09	1.60E-06	20.956%	2.77E-06	22.573%
45%	2.03E+09	2.21E-06	24.649%	3.82E-06	26.520%
50%	2.50E+09	3.05E-06	28.946%	5.37E-06	31.454%

Table H.16(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 1477 kN.

		P=1477 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0.54894628	0.7147934	0.3991942	1.14%	1.23%	0.87%
10%	1.00E+08	2.18233471	2.8745661	1.3120661	2.28%	2.48%	1.57%
15%	2.25E+08	4.88008264	6.4101033	2.6925826	3.41%	3.70%	2.25%
20%	4.00E+08	8.7831405	11.59093	4.5059711	4.58%	4.97%	2.91%
25%	6.25E+08	13.9944008	18.529112	2.685124	5.78%	6.29%	0.84%
30%	9.00E+08	20.4961983	26.382231	9.3025	6.99%	7.50%	4.18%
35%	1.23E+09	27.2294215	27.610248	10.681012	8.06%	7.67%	4.48%
40%	1.60E+09	38.7223347	32.905868	15.423471	9.61%	8.38%	5.39%
45%	2.03E+09	50.2809917	36.328017	19.041322	10.95%	8.80%	5.98%
50%	2.50E+09	55.0294215	39.804628	22.996384	11.46%	9.21%	6.58%

Table H.16(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 1832 kN.

		P=1832 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0.5831405	0.911157	1.30167	0.89%	1.05%	1.16%
10%	1.00E+08	2.2363843	3.3389256	4.86002	1.75%	2.00%	2.24%
15%	2.25E+08	5.1240496	7.6880165	11.253	2.64%	3.04%	3.41%
20%	4.00E+08	10.095062	15.352149	21.8344	3.71%	4.29%	4.76%
25%	6.25E+08	15.927355	23.832149	34.4889	4.66%	3.14%	5.98%
30%	9.00E+08	22.865785	33.745537	49.0637	5.58%	6.36%	7.13%
35%	1.23E+09	29.752066	43.620021	51.84	6.37%	7.23%	7.33%
40%	1.60E+09	41.896198	61.195062	60.3446	7.55%	8.57%	7.91%
45%	2.03E+09	53.955702	78.725289	65.4628	8.57%	9.72%	8.24%
50%	2.50E+09	69.494959	100.81986	70.3311	9.73%	11.00%	8.54%

Table H.16(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 2044 kN.

		P=2044 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0.49	0.8264463	1.2913223	0.71%	0.86%	0.99%
10%	1.00E+08	1.9983678	3.4731405	5.3739669	1.43%	1.75%	2.02%
15%	2.25E+08	4.5252893	7.6880165	11.933884	2.16%	2.61%	3.01%
20%	4.00E+08	8.4628099	14.578512	22.347107	2.95%	3.60%	4.12%
25%	6.25E+08	12.829421	22.778926	34.917355	3.63%	4.49%	5.15%
30%	9.00E+08	19.280083	31.819855	50.280992	4.45%	5.31%	6.18%
35%	1.23E+09	26.01	41.837376	66.200413	5.17%	6.09%	7.09%
40%	1.60E+09	37.154566	58.383492	92.859504	6.18%	7.19%	8.40%
45%	2.03E+09	47.924153	75.058595	120.00207	7.02%	8.16%	9.55%
50%	2.50E+09	60.344649	93.47374	133.29752	7.88%	9.10%	10.07%

Table H.16(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'EI' and lateral load 2283 kN.

		P=2283 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	2.50E+07	0.4049587	0.6694215	1.3966942	0.56%	0.66%	0.87%
10%	1.00E+08	1.6198347	2.677686	5.5867769	1.12%	1.32%	1.75%
15%	2.25E+08	3.4731405	6.0247934	12.570248	1.63%	1.98%	2.62%
20%	4.00E+08	6.25	10.710744	21.919421	2.19%	2.64%	3.47%
25%	6.25E+08	9.8367769	17.109504	33.85124	2.75%	3.34%	4.31%
30%	9.00E+08	14.233471	25	47.735537	3.31%	4.04%	5.11%
35%	1.23E+09	17.869835	32.283058	60.415289	3.71%	4.59%	5.75%
40%	1.60E+09	25.917355	45.869835	84.305785	4.47%	5.47%	6.80%
45%	2.03E+09	33.85124	59.010331	107.40496	5.10%	6.21%	7.67%
50%	2.50E+09	41.076446	72.25	131.20661	5.62%	6.87%	8.48%

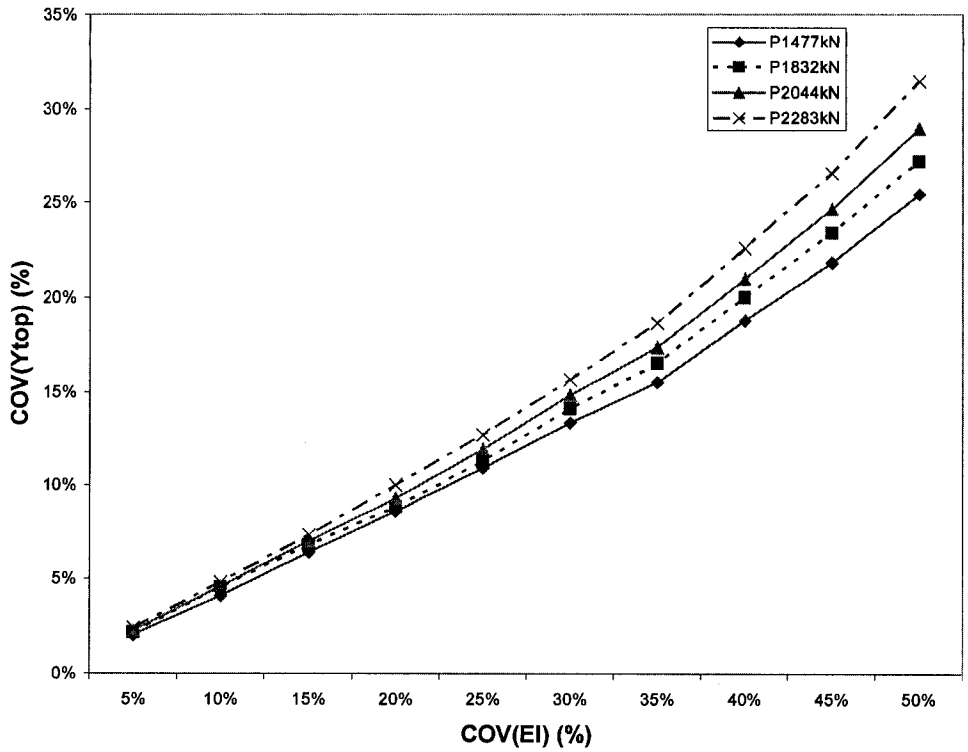

Fig. H.7 COV(Y_{Top}) for varying COV(EI) in fixed head long (10T) pile group with spacing (3D).

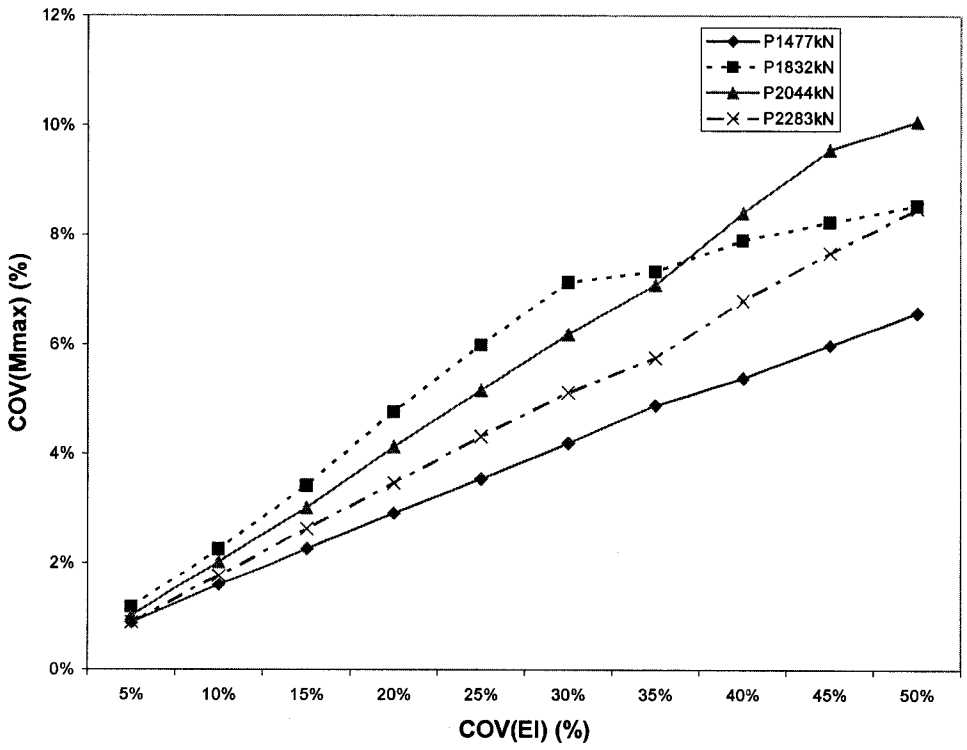

Fig. H.8(a) COV(M_{Max}) for varying COV(EI) for pile C in fixed head long pile group with spacing (3D).

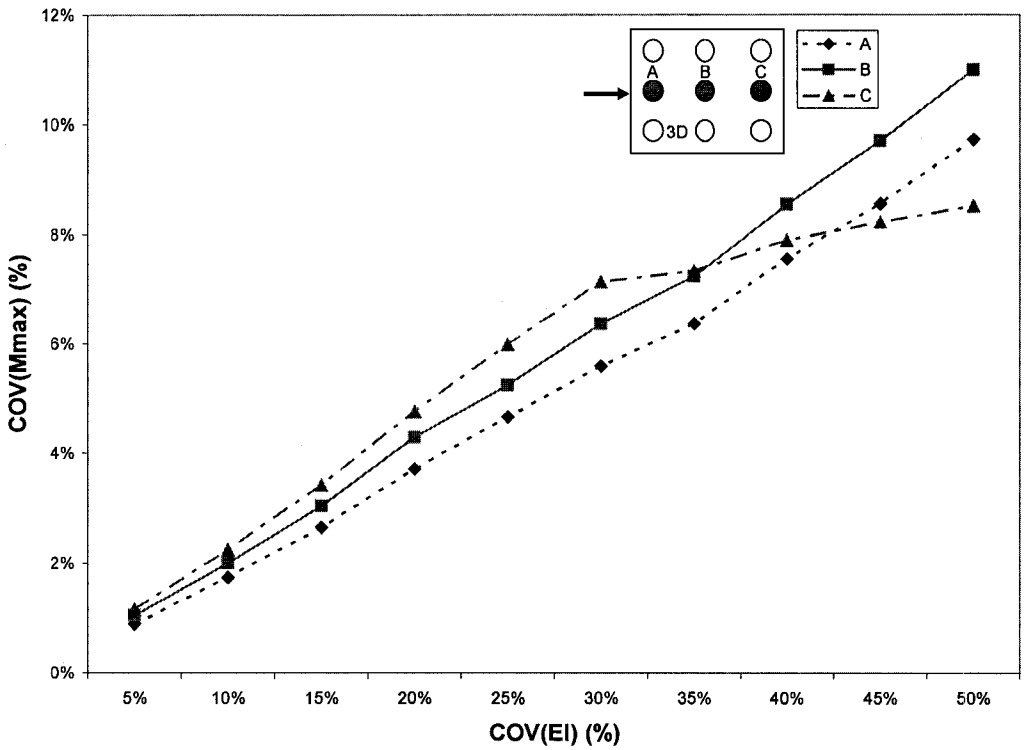

Fig. H.8(b) COV(M_{Max}) for varying COV(EI) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (3D) at the optimum lateral load 1832 kN.

H.1.5 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (3D) and with 'k' as varying random design variable

Table H.17. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 1477 kN and 1832 kN.

			P=1477 kN (150, 160, 190 kN)				P=1832 kN (180, 200, 230 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00355	64.48	68.41	71.97	0.00503	85.3	91.25	98.48
45%	3.75E+09	74800	0.00354	64.5	68.39	72.89	0.00502	85.43	91.34	98.51
40%	2.96E+09	81600	0.00354	64.58	68.45	72.93	0.00502	85.51	91.38	98.51
35%	2.27E+09	88400	0.00354	64.64	68.48	72.97	0.00502	85.59	91.39	98.51
30%	1.66E+09	95200	0.00354	64.67	68.48	72.96	0.00502	85.66	91.41	98.51
25%	1.16E+09	102000	0.00354	64.68	68.49	72.95	0.00502	85.71	91.43	98.49
20%	7.40E+08	108800	0.00354	64.69	68.5	72.95	0.00502	85.76	91.44	98.46
15%	4.16E+08	115600	0.00354	64.7	68.5	72.94	0.00502	85.76	91.46	98.45
10%	1.85E+08	122400	0.00354	64.71	68.49	72.93	0.005	85.69	91.3	98.26
5%	4.62E+07	129200	0.00354	64.72	68.48	72.93	0.005	85.69	91.31	98.24
0%	0.00E+00	136000	0.00354	64.73	68.47	72.92	0.005	85.69	91.32	98.23
5%	4.62E+07	142800	0.00354	64.73	68.47	72.92	0.005	85.69	91.34	98.21
10%	1.85E+08	149600	0.00354	64.74	68.46	72.91	0.005	85.69	91.35	98.2
15%	4.16E+08	156400	0.00354	64.75	68.45	72.9	0.005	85.69	91.36	98.19
20%	7.40E+08	163200	0.00354	64.75	68.45	72.89	0.005	85.69	91.37	98.18
25%	1.16E+09	170000	0.00354	64.76	68.44	72.88	0.005	85.69	91.39	98.17
30%	1.66E+09	176800	0.00354	64.77	68.44	72.87	0.005	85.69	91.4	98.16
35%	2.27E+09	183600	0.00354	64.78	68.43	72.87	0.005	85.69	91.41	98.15
40%	2.96E+09	190400	0.00354	64.79	68.43	72.86	0.005	85.69	91.42	98.14
45%	3.75E+09	197200	0.00354	64.79	68.42	72.86	0.005	85.69	91.43	98.14
50%	4.62E+09	204000	0.00354	64.8	68.42	72.86	0.005	85.69	91.43	91.13

Table H.18. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 2044 kN and 2283 kN.

			P=2044 kN (200, 220, 260 kN)				P=2283 kN (220, 250, 290 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00603	98.34	105.8	114.8	0.00738	114.1	123.5	134.8
45%	3.75E+09	74800	0.00603	98.51	105.8	114.8	0.00737	114	123.6	134.9
40%	2.96E+09	81600	0.00603	98.63	105.8	114.8	0.00737	114	123.8	134.9
35%	2.27E+09	88400	0.00603	98.63	105.9	114.8	0.00737	114	123.8	134.9
30%	1.66E+09	95200	0.00603	98.64	106	114.8	0.00737	114	123.8	134.9
25%	1.16E+09	102000	0.00603	98.63	106	114.8	0.00737	114	123.8	135
20%	7.40E+08	108800	0.00603	98.62	106.1	114.8	0.00737	114	123.8	135
15%	4.16E+08	115600	0.00603	98.62	106.1	114.8	0.00737	114	123.8	135
10%	1.85E+08	122400	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135
5%	4.62E+07	129200	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135
0%	0.00E+00	136000	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135.1
5%	4.62E+07	142800	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135.1
10%	1.85E+08	149600	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135.1
15%	4.16E+08	156400	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135.1
20%	7.40E+08	163200	0.00603	98.62	106.2	114.7	0.00737	114	123.8	135.1
25%	1.16E+09	170000	0.00603	98.62	106.2	114.7	0.00735	114	123.8	135.1
30%	1.66E+09	176800	0.00603	98.62	106.2	114.7	0.00735	114	123.8	135.1
35%	2.27E+09	183600	0.00603	98.62	106.2	114.7	0.00735	114	123.8	135.1
40%	2.96E+09	190400	0.00603	98.62	106.2	114.7	0.00735	114	123.8	135.1
45%	3.75E+09	197200	0.00603	98.62	106.2	114.7	0.00735	114	123.8	135.1
50%	4.62E+09	204000	0.00603	98.62	106.2	114.7	0.00735	113.9	123.7	135

Table H.19(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 1477 kN and 1832 kN.

		P=1477 kN		P=1832 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	1.00E-10	0.200%
20%	7.40E+08	0.00E+00	0.000%	1.00E-10	0.200%
25%	1.16E+09	0.00E+00	0.000%	1.00E-10	0.200%
30%	1.66E+09	0.00E+00	0.000%	1.00E-10	0.200%
35%	2.27E+09	0.00E+00	0.000%	1.00E-10	0.200%
40%	2.96E+09	0.00E+00	0.000%	1.00E-10	0.200%
45%	3.75E+09	0.00E+00	0.000%	1.00E-10	0.200%
50%	4.62E+09	2.50E-11	0.141%	2.25E-10	0.300%

Table H.19(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (3D) and with varying 'k' and lateral load 2044 kN and 2283 kN.

		P=2044 kN		P=2283 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	0.00E+00	0.000%
20%	7.40E+08	0.00E+00	0.000%	0.00E+00	0.000%
25%	1.16E+09	0.00E+00	0.000%	1.00E-10	0.136%
30%	1.66E+09	0.00E+00	0.000%	1.00E-10	0.136%
35%	2.27E+09	0.00E+00	0.000%	1.00E-10	0.136%
40%	2.96E+09	0.00E+00	0.000%	1.00E-10	0.136%
45%	3.75E+09	0.00E+00	0.000%	1.00E-10	0.136%
50%	4.62E+09	0.00E+00	0.000%	2.25E-10	0.204%

Table H.20(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 1477 kN.

		P=1477 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	2.5E-05	2.5E-05	2.5E-05	0.01%	0.01%	0.01%
10%	1.85E+08	0.000225	0.000225	0.0001	0.02%	0.02%	0.01%
15%	4.16E+08	0.000625	0.000625	0.0004	0.04%	0.04%	0.03%
20%	7.40E+08	0.0009	0.000625	0.0009	0.05%	0.04%	0.04%
25%	1.16E+09	0.0016	0.000625	0.00049	0.06%	0.04%	0.03%
30%	1.66E+09	0.0025	0.0004	0.002025	0.08%	0.03%	0.06%
35%	2.27E+09	0.0049	0.000625	0.0025	0.11%	0.04%	0.07%
40%	2.96E+09	0.011025	1E-04	0.001225	0.16%	0.01%	0.05%
45%	3.75E+09	0.021025	0.000225	0.000225	0.22%	0.02%	0.02%
50%	4.62E+09	0.0256	2.5E-05	0.198025	0.25%	0.01%	0.61%

Table H.20(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 1832 kN.

		P=1832 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0.000225	0.000225	0.00%	0.02%	0.02%
10%	1.85E+08	0	0.000625	0.0009	0.00%	0.03%	0.03%
15%	4.16E+08	0.001225	0.0025	0.0169	0.04%	0.05%	0.13%
20%	7.40E+08	0.001225	0.001225	0.0196	0.04%	0.04%	0.14%
25%	1.16E+09	1E-04	0.0004	0.0256	0.01%	0.02%	0.16%
30%	1.66E+09	0.000225	2.5E-05	0.030625	0.02%	0.01%	0.18%
35%	2.27E+09	0.0025	1E-04	0.0324	0.06%	0.01%	0.18%
40%	2.96E+09	0.0081	0.0004	0.034225	0.11%	0.02%	0.19%
45%	3.75E+09	0.0169	0.002025	0.034225	0.15%	0.05%	0.19%
50%	4.62E+09	0.038025	0.0081	13.505625	0.23%	0.10%	3.74%

Table H.20(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 2044 kN.

		P=2044 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0	0	0.00%	0.00%	0.00%
10%	1.85E+08	0	0	0	0.00%	0.00%	0.00%
15%	4.16E+08	0	0.0025	0.0025	0.00%	0.05%	0.04%
20%	7.40E+08	0	0.0025	0.0025	0.00%	0.05%	0.04%
25%	1.16E+09	2.5E-05	0.01	0.0025	0.01%	0.09%	0.04%
30%	1.66E+09	1E-04	0.01	0.0025	0.01%	0.09%	0.04%
35%	2.27E+09	2.5E-05	0.0225	0.0025	0.01%	0.14%	0.04%
40%	2.96E+09	2.5E-05	0.04	0.0025	0.01%	0.19%	0.04%
45%	3.75E+09	0.003025	0.04	0.0025	0.06%	0.19%	0.04%
50%	4.62E+09	0.0196	0.04	0.0025	0.14%	0.19%	0.04%

Table H.20(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'k' and lateral load 2283 kN.

		P=2283 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0	0.0025	0.00%	0.00%	0.04%
10%	1.85E+08	0	0	0.0025	0.00%	0.00%	0.04%
15%	4.16E+08	0	0	0.0025	0.00%	0.00%	0.04%
20%	7.40E+08	0	0	0.0025	0.00%	0.00%	0.04%
25%	1.16E+09	0	0	0.0025	0.00%	0.00%	0.04%
30%	1.66E+09	0	0	0.01	0.00%	0.00%	0.07%
35%	2.27E+09	0	0	0.01	0.00%	0.00%	0.07%
40%	2.96E+09	0	0	0.01	0.00%	0.00%	0.07%
45%	3.75E+09	0	0.01	0.01	0.00%	0.08%	0.07%
50%	4.62E+09	0.01	0.01	0.01	0.09%	0.08%	0.07%

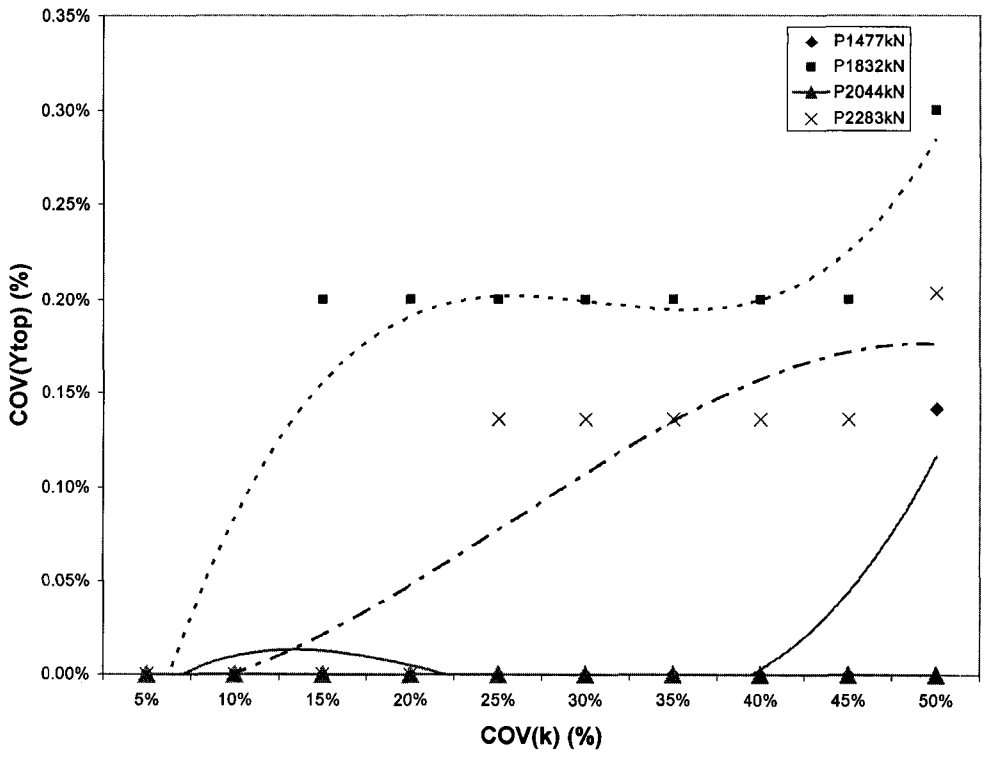

Fig. H.9 COV(Y_{Top}) for varying COV(k) in fixed head long (10T) pile group with spacing (3D).

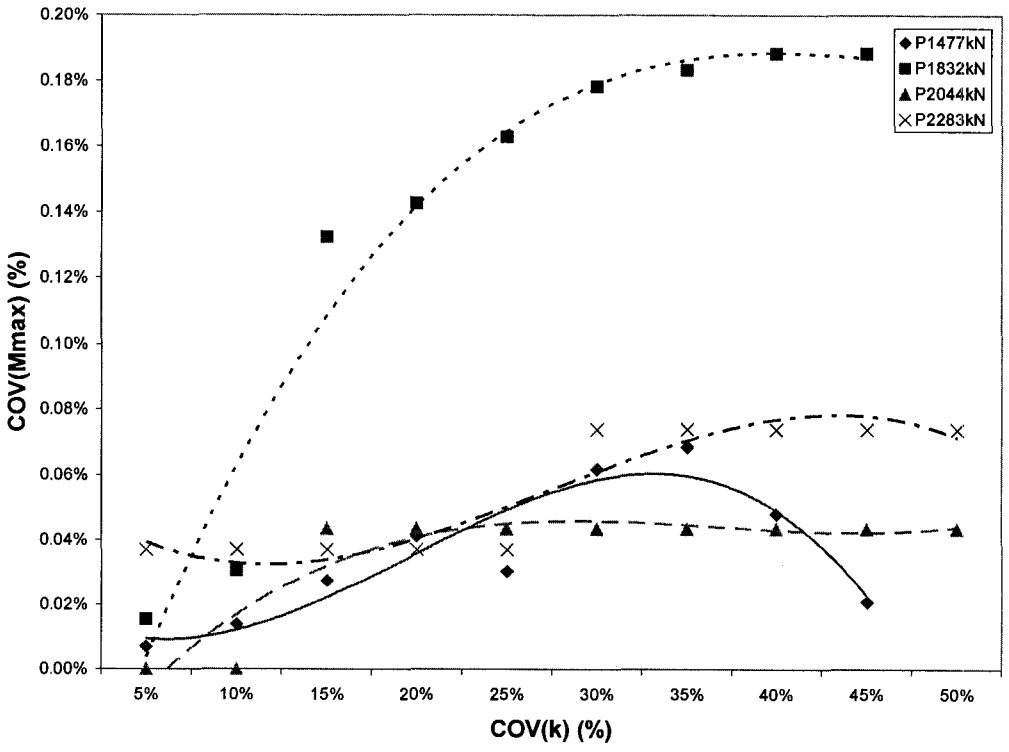

Fig. H.10(a) COV(M_{Max}) for varying COV(k) for pile C in fixed head long pile group with spacing (3D).

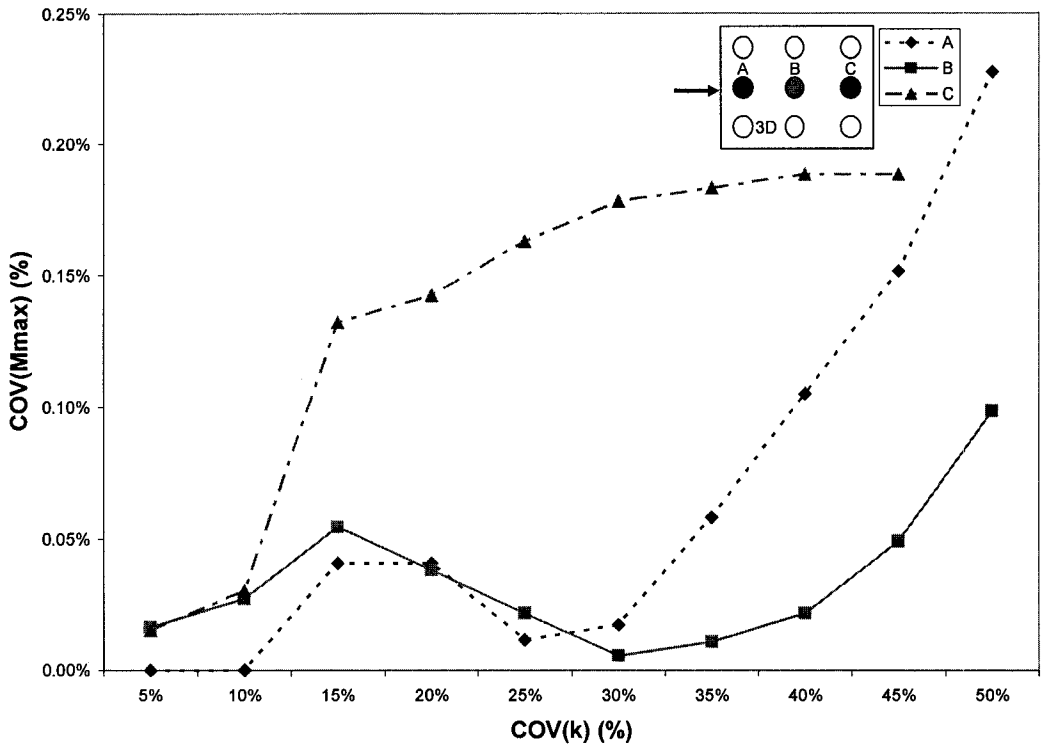

Fig. H.10(b) COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (3D) at the optimum lateral load 1832 kN.

H.1.6 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (3D) and with 'γ'' as varying random design variable

Table H.21. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 1477 kN and 1832 kN.

			P=1477 kN (150, 160, 190 kN)				P=1832 kN (180, 200, 230 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00355	64.87	68.64	73.1	0.00502	85.86	91.52	98.45
45%	7.049025	3.245	0.00354	64.85	68.62	73.08	0.00501	85.84	91.5	98.42
40%	5.5696	3.54	0.00354	64.83	68.6	73.07	0.00501	85.82	91.48	98.4
35%	4.264225	3.835	0.00354	64.82	68.58	73.05	0.00501	85.8	91.46	98.38
30%	3.1329	4.13	0.00354	64.8	68.57	73.03	0.00501	85.78	91.44	98.35
25%	2.175625	4.425	0.00354	64.79	68.55	73.01	0.00501	85.76	91.42	98.33
20%	1.3924	4.72	0.00354	64.77	68.53	72.99	0.00501	85.75	91.4	98.31
15%	0.783225	5.015	0.00354	64.76	68.52	72.97	0.00501	85.73	91.38	98.28
10%	0.3481	5.31	0.00354	64.74	68.5	72.95	0.005	85.71	91.35	98.26
5%	0.087025	5.605	0.00354	64.73	68.48	72.93	0.005	85.69	91.33	98.23
0%	0	5.9	0.00354	64.71	68.46	72.91	0.005	85.67	91.31	98.21
5%	0.087025	6.195	0.00353	64.7	68.45	72.89	0.005	85.66	91.29	98.19
10%	0.3481	6.49	0.00353	64.68	68.43	72.87	0.005	85.64	91.27	98.16
15%	0.783225	6.785	0.00353	64.66	68.41	72.85	0.00499	85.62	91.25	98.14
20%	1.3924	7.08	0.00353	64.65	68.39	72.83	0.00499	85.6	91.23	98.11
25%	2.175625	7.375	0.00353	64.63	68.38	72.81	0.00499	85.58	91.21	98.09
30%	3.1329	7.67	0.00353	64.62	68.36	72.79	0.00499	85.56	91.19	98.07
35%	4.264225	7.965	0.00353	64.6	68.34	72.77	0.00499	85.55	91.16	98.05
40%	5.5696	8.26	0.00353	64.59	68.33	72.75	0.00499	85.53	91.14	98.02
45%	7.049025	8.555	0.00353	64.57	68.31	72.73	0.00499	85.51	91.12	98
50%	8.7025	8.85	0.00353	64.56	68.29	72.71	0.00499	85.49	91.1	97.97

Table H.22. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 2044 kN and 2283 kN.

			P=2044 kN (200, 220, 260 kN)				P=2283 kN (220, 250, 290 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00605	98.83	106.5	115	0.00739	114.2	124	135.4
45%	7.049025	3.245	0.00605	98.81	106.4	115	0.00739	114.2	124	135.3
40%	5.5696	3.54	0.00605	98.79	106.4	115	0.00739	114.2	124	135.3
35%	4.264225	3.835	0.00605	98.77	106.4	115	0.00739	114.1	124	135.3
30%	3.1329	4.13	0.00604	98.72	106.3	114.9	0.00738	114.1	123.9	135.2
25%	2.175625	4.425	0.00604	98.7	106.3	114.9	0.00738	114.1	123.9	135.2
20%	1.3924	4.72	0.00604	98.68	106.3	114.8	0.00738	114.1	123.9	135.2
15%	0.783225	5.015	0.00603	98.66	106.3	114.8	0.00738	114.1	123.9	135.1
10%	0.3481	5.31	0.00603	98.64	106.2	114.8	0.00737	114	123.8	135.1
5%	0.087025	5.605	0.00603	98.62	106.2	114.8	0.00737	114	123.8	135.1
0%	0	5.9	0.00603	98.6	106.2	114.7	0.00737	114	123.8	135
5%	0.087025	6.195	0.00603	98.58	106.2	114.7	0.00737	114	123.8	135
10%	0.3481	6.49	0.00602	98.56	106.1	114.7	0.00737	113.9	123.7	135
15%	0.783225	6.785	0.00602	98.54	106.1	114.7	0.00737	113.9	123.7	135
20%	1.3924	7.08	0.00602	98.52	106.1	114.6	0.00737	113.9	123.7	134.9
25%	2.175625	7.375	0.00602	98.5	106.1	114.6	0.00736	113.9	123.6	134.9
30%	3.1329	7.67	0.00602	98.48	106	114.6	0.00736	113.9	123.6	134.9
35%	4.264225	7.965	0.00601	98.46	106	114.5	0.00736	113.8	123.6	134.8
40%	5.5696	8.26	0.00601	98.44	106	114.5	0.00736	113.8	123.6	134.8
45%	7.049025	8.555	0.00601	98.42	106	114.5	0.00736	113.8	123.5	134.8
50%	8.7025	8.85	0.00601	98.4	106	114.4	0.00735	113.8	123.5	134.7

Table H.23(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 1477 kN and 1832 kN.

		P=1477 kN		P=1832 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	2.5E-11	0.141%	0	0.000%
10%	0.3481	2.5E-11	0.141%	0	0.000%
15%	0.783225	2.5E-11	0.141%	1E-10	0.200%
20%	1.3924	2.5E-11	0.141%	1E-10	0.200%
25%	2.175625	2.5E-11	0.141%	1E-10	0.200%
30%	3.1329	2.5E-11	0.141%	1E-10	0.200%
35%	4.264225	2.5E-11	0.141%	1E-10	0.200%
40%	5.5696	2.5E-11	0.141%	1E-10	0.200%
45%	7.049025	2.5E-11	0.141%	1E-10	0.200%
50%	8.7025	1E-10	0.282%	2.25E-10	0.300%

Table H.23(b) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 2044 kN and 2283 kN.

		P=2044 kN		P=2283 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0	0.000%	0	0.000%
10%	0.3481	2.5E-11	0.083%	0	0.000%
15%	0.783225	2.5E-11	0.083%	2.5E-11	0.068%
20%	1.3924	1E-10	0.166%	2.5E-11	0.068%
25%	2.175625	1E-10	0.166%	1E-10	0.136%
30%	3.1329	1E-10	0.166%	1E-10	0.136%
35%	4.264225	4E-10	0.332%	2.25E-10	0.204%
40%	5.5696	4E-10	0.332%	2.25E-10	0.204%
45%	7.049025	4E-10	0.332%	2.25E-10	0.204%
50%	8.7025	4E-10	0.332%	4E-10	0.271%

Table H.24(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 1477 kN.

		P=1477 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.000225	0.000225	0.0004	0.02%	0.02%	0.03%
10%	0.3481	0.0009	0.001225	0.0016	0.05%	0.05%	0.05%
15%	0.783225	0.0025	0.003025	0.0036	0.08%	0.08%	0.08%
20%	1.3924	0.0036	0.0049	0.0064	0.09%	0.10%	0.11%
25%	2.175625	0.0064	0.007225	0.004	0.12%	0.12%	0.09%
30%	3.1329	0.0081	0.011025	0.0144	0.14%	0.15%	0.16%
35%	4.264225	0.0121	0.0144	0.0196	0.17%	0.18%	0.19%
40%	5.5696	0.0144	0.018225	0.0256	0.19%	0.20%	0.22%
45%	7.049025	0.0196	0.024025	0.030625	0.22%	0.23%	0.24%
50%	8.7025	0.024025	0.030625	0.038025	0.24%	0.26%	0.27%

Table H.24(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 1832 kN.

		P=1832 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.000225	0.0004	0.0004	0.02%	0.02%	0.02%
10%	0.3481	0.001225	0.0016	0.0025	0.04%	0.04%	0.05%
15%	0.783225	0.003025	0.004225	0.0049	0.06%	0.07%	0.07%
20%	1.3924	0.005625	0.007225	0.01	0.09%	0.09%	0.10%
25%	2.175625	0.0081	0.011025	0.0144	0.11%	0.11%	0.12%
30%	3.1329	0.0121	0.015625	0.0196	0.13%	0.14%	0.14%
35%	4.264225	0.015625	0.0225	0.027225	0.15%	0.16%	0.17%
40%	5.5696	0.021025	0.0289	0.0361	0.17%	0.19%	0.19%
45%	7.049025	0.027225	0.0361	0.0441	0.19%	0.21%	0.21%
50%	8.7025	0.034225	0.0441	0.0576	0.22%	0.23%	0.24%

Table H.24(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 2044 kN.

		P=2044 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.0004	0	0.0025	0.02%	0.00%	0.04%
10%	0.3481	0.0016	0.0025	0.0025	0.04%	0.05%	0.04%
15%	0.783225	0.0036	0.01	0.0025	0.06%	0.09%	0.04%
20%	1.3924	0.0064	0.01	0.01	0.08%	0.09%	0.09%
25%	2.175625	0.01	0.01	0.0225	0.10%	0.09%	0.13%
30%	3.1329	0.0144	0.0225	0.0225	0.12%	0.14%	0.13%
35%	4.264225	0.024025	0.04	0.0625	0.16%	0.19%	0.22%
40%	5.5696	0.030625	0.04	0.0625	0.18%	0.19%	0.22%
45%	7.049025	0.038025	0.04	0.0625	0.20%	0.19%	0.22%
50%	8.7025	0.046225	0.0625	0.09	0.22%	0.24%	0.26%

Table H.24(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (3D) and with varying 'γ'' and lateral load 2283 kN.

		P=2283 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0	0	0.0025	0.00%	0.00%	0.04%
10%	0.3481	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
15%	0.783225	0.01	0.01	0.0025	0.09%	0.08%	0.04%
20%	1.3924	0.01	0.01	0.0225	0.09%	0.08%	0.11%
25%	2.175625	0.01	0.0225	0.0225	0.09%	0.12%	0.11%
30%	3.1329	0.01	0.0225	0.0225	0.09%	0.12%	0.11%
35%	4.264225	0.0225	0.04	0.0625	0.13%	0.16%	0.19%
40%	5.5696	0.04	0.04	0.0625	0.18%	0.16%	0.19%
45%	7.049025	0.04	0.0625	0.0625	0.18%	0.20%	0.19%
50%	8.7025	0.04	0.0625	0.1225	0.18%	0.20%	0.26%

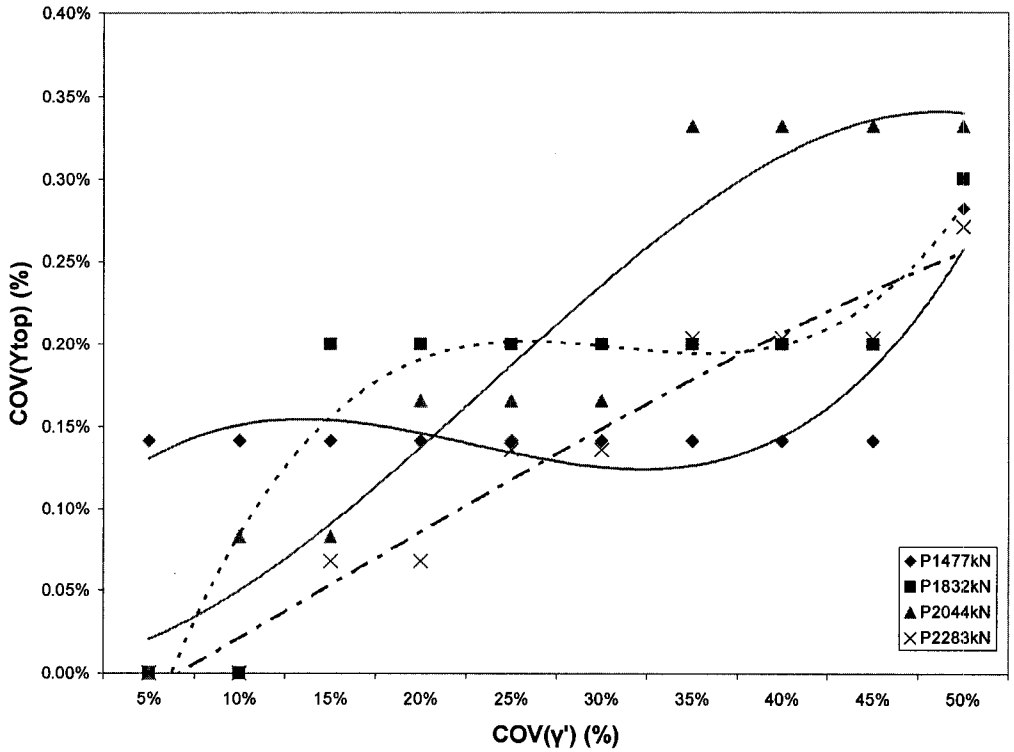

Fig. H.11 COV(Y_{Top}) for varying COV(γ') in fixed head long (10T) pile group with spacing (3D).

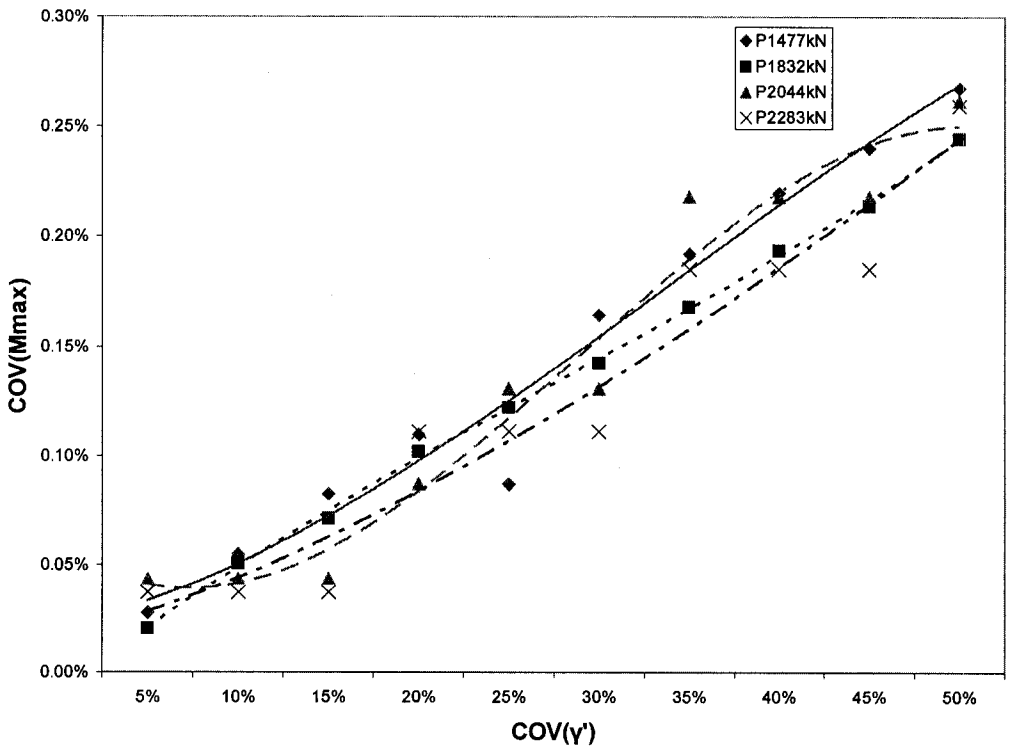

Fig. H.12(a) COV(M_{Max}) for varying COV(γ') for pile C in fixed head long pile group with spacing (3D).

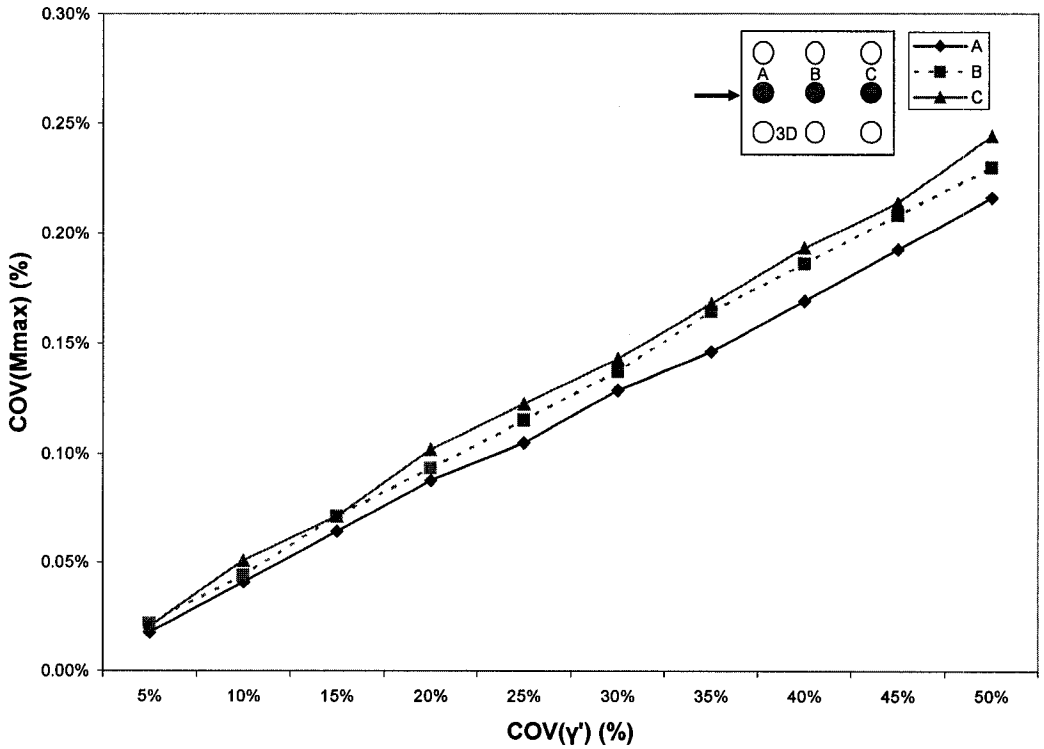

Fig. H.12 COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (3D) at the optimum lateral load 1832 kN.

H.2 Reliability analysis of fixed head long pile (10T) group with spacing (3D)

H.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 1477 kN

$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00946$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06\ m^2$

Table H.25 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 1477 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	8.10E-09	6.77E-06	3.64	3.06E-08	6.79E-06	3.63
10%	6.76E-06	3.42E-08	6.79E-06	3.63	1.19E-07	6.88E-06	3.61
15%	6.76E-06	8.12E-08	6.84E-06	3.62	2.81E-07	7.04E-06	3.57
20%	6.76E-06	1.56E-07	6.92E-06	3.60	5.04E-07	7.26E-06	3.51
25%	6.76E-06	2.55E-07	7.02E-06	3.57	8.37E-07	7.60E-06	3.43
30%	6.76E-06	3.91E-07	7.15E-06	3.54	1.28E-06	8.04E-06	3.34
35%	6.76E-06	Failed	Failed	Failed	1.92E-06	8.68E-06	3.21
40%	6.76E-06	Failed	Failed	Failed	2.86E-06	9.62E-06	3.05
45%	6.76E-06	Failed	Failed	Failed	4.12E-06	1.09E-05	2.87
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table H.26 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'ε_{50}' and 'EI' and applied lateral load 1477 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	4.90E-09	6.76E-06	3.64	5.29E-09	6.77E-06	3.64
10%	6.76E-06	1.96E-08	6.78E-06	3.63	2.12E-08	6.78E-06	3.63
15%	6.76E-06	4.62E-08	6.81E-06	3.63	5.17E-08	6.81E-06	3.62
20%	6.76E-06	8.41E-08	6.84E-06	3.62	9.27E-08	6.85E-06	3.61
25%	6.76E-06	1.26E-07	6.89E-06	3.61	1.49E-07	6.91E-06	3.60
30%	6.76E-06	1.85E-07	6.94E-06	3.59	2.23E-07	6.98E-06	3.58
35%	6.76E-06	2.55E-07	7.02E-06	3.57	3.03E-07	7.06E-06	3.56
40%	6.76E-06	3.31E-07	7.09E-06	3.55	4.40E-07	7.20E-06	3.53
45%	6.76E-06	4.23E-07	7.18E-06	3.53	5.97E-07	7.36E-06	3.49
50%	6.76E-06	5.26E-07	7.29E-06	3.50	8.10E-07	7.57E-06	3.44

Table H.27 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 1477 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
10%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
15%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
20%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
25%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
30%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
35%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
40%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
45%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
50%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64

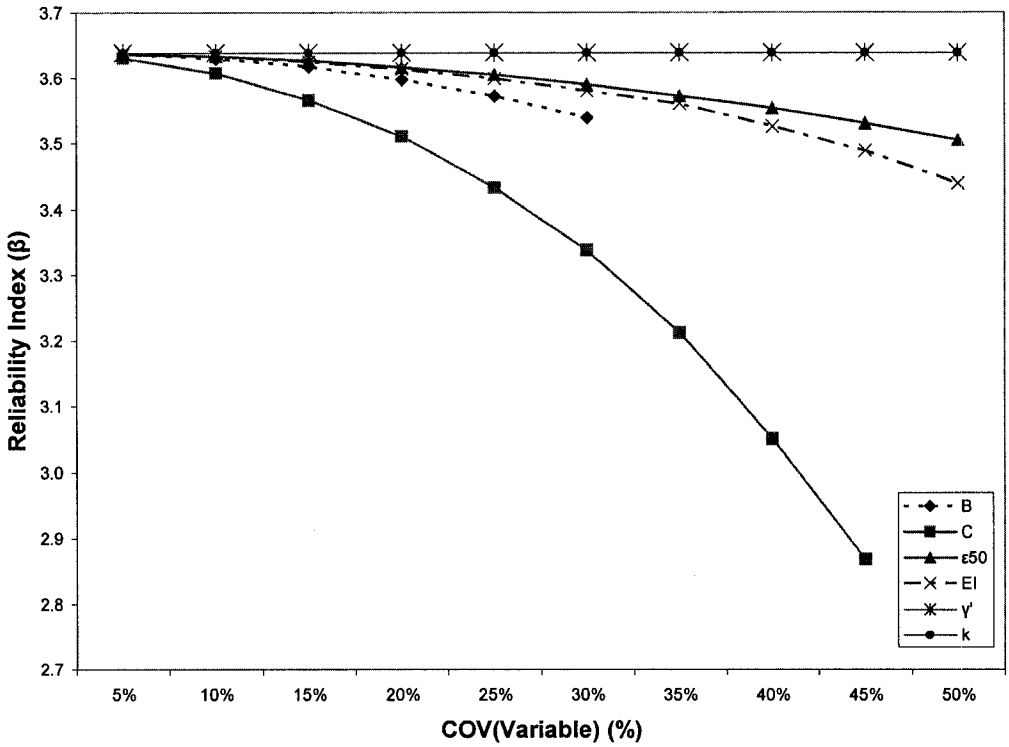

Fig. H.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (3D) at 1477 kN lateral load.

For lateral load 1832 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00826 \text{ m}$$

Table H.28 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 1832 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	2.10E-08	6.78E-06	3.07	6.00E-08	6.82E-06	3.06
10%	6.76E-06	9.00E-08	6.85E-06	3.06	2.60E-07	7.02E-06	3.02
15%	6.76E-06	2.30E-07	6.99E-06	3.03	6.16E-07	7.38E-06	2.95
20%	6.76E-06	4.36E-07	7.20E-06	2.98	1.16E-06	7.92E-06	2.84
25%	6.76E-06	7.92E-07	7.55E-06	2.91	1.99E-06	8.75E-06	2.70
30%	6.76E-06	1.28E-06	8.04E-06	2.82	3.19E-06	9.95E-06	2.54
35%	6.76E-06	Failed	Failed	Failed	4.88E-06	1.16E-05	2.34
40%	6.76E-06	Failed	Failed	Failed	7.26E-06	1.40E-05	2.14
45%	6.76E-06	Failed	Failed	Failed	1.13E-05	1.80E-05	1.88
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table H.29 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'ε_{50}' and 'EI' and applied lateral load 1832 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	9.02E-09	6.77E-06	3.07	1.19E-08	6.77E-06	3.07
10%	6.76E-06	3.61E-08	6.80E-06	3.07	5.17E-08	6.81E-06	3.07
15%	6.76E-06	8.41E-08	6.84E-06	3.06	1.16E-07	6.88E-06	3.05
20%	6.76E-06	1.44E-07	6.90E-06	3.04	1.94E-07	6.95E-06	3.03
25%	6.76E-06	2.26E-07	6.99E-06	3.03	3.18E-07	7.08E-06	3.01
30%	6.76E-06	3.31E-07	7.09E-06	3.00	4.96E-07	7.26E-06	2.97
35%	6.76E-06	4.49E-07	7.21E-06	2.98	6.84E-07	7.44E-06	2.93
40%	6.76E-06	6.08E-07	7.37E-06	2.95	1.00E-06	7.76E-06	2.87
45%	6.76E-06	7.74E-07	7.53E-06	2.91	1.36E-06	8.12E-06	2.81
50%	6.76E-06	9.41E-07	7.70E-06	2.88	1.85E-06	8.61E-06	2.73

Table H.30 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 1832 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
10%	6.76E-06	0.00E+00	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
15%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
20%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
25%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
30%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
35%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
40%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
45%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
50%	6.76E-06	2.25E-10	6.76E-06	3.08	2.25E-10	6.76E-06	3.08

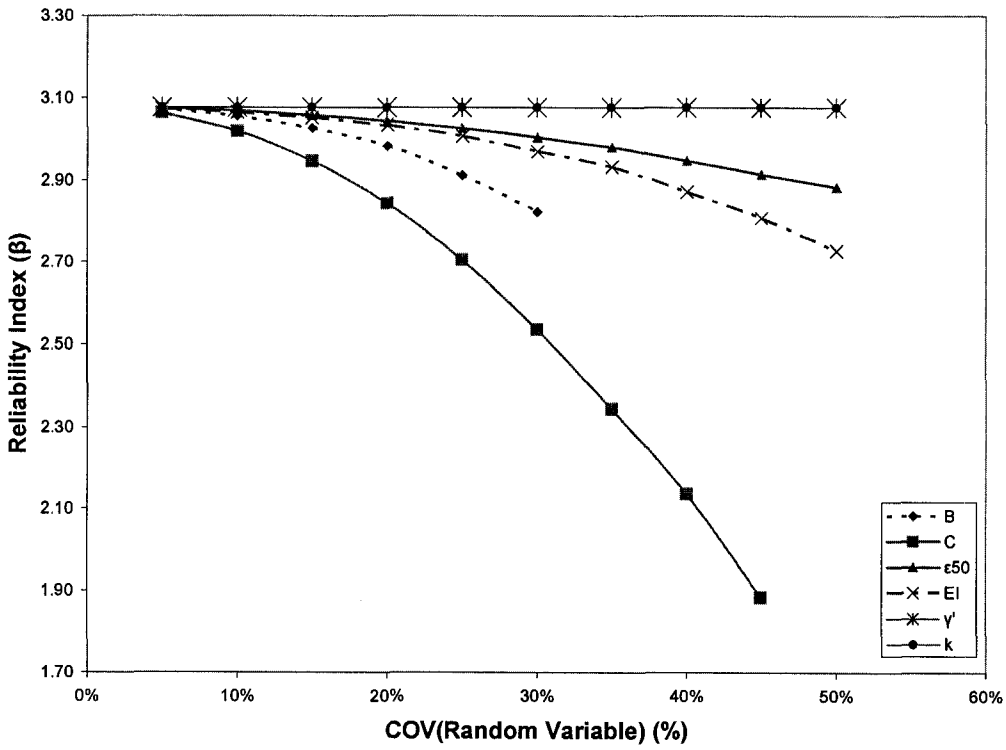

Fig. H.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (3D) at 1832 kN lateral load.

For lateral load 2044 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00697 \text{ m}$$

Table H.31 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 2044 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	4.00E-08	6.80E-06	2.67	1.12E-07	6.87E-06	2.66
10%	6.76E-06	1.81E-07	6.94E-06	2.65	4.36E-07	7.20E-06	2.60
15%	6.76E-06	4.49E-07	7.21E-06	2.60	1.02E-06	7.78E-06	2.50
20%	6.76E-06	9.12E-07	7.67E-06	2.52	1.95E-06	8.71E-06	2.36
25%	6.76E-06	1.59E-06	8.35E-06	2.41	3.31E-06	1.01E-05	2.20
30%	6.76E-06	2.72E-06	9.48E-06	2.26	5.34E-06	1.21E-05	2.00
35%	6.76E-06	Failed	Failed	Failed	8.29E-06	1.51E-05	1.80
40%	6.76E-06	Failed	Failed	Failed	1.30E-05	1.98E-05	1.57
45%	6.76E-06	Failed	Failed	Failed	2.05E-05	2.73E-05	1.33
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table H.32 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'ε_{50}' and 'EI' and applied lateral load 2044 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.10E-08	6.77E-06	2.68	1.86E-08	6.78E-06	2.68
10%	6.76E-06	4.20E-08	6.80E-06	2.67	7.69E-08	6.84E-06	2.67
15%	6.76E-06	1.02E-07	6.86E-06	2.66	1.79E-07	6.94E-06	2.65
20%	6.76E-06	1.85E-07	6.94E-06	2.64	3.13E-07	7.07E-06	2.62
25%	6.76E-06	2.86E-07	7.05E-06	2.63	5.16E-07	7.28E-06	2.58
30%	6.76E-06	4.10E-07	7.17E-06	2.60	8.02E-07	7.56E-06	2.53
35%	6.76E-06	5.63E-07	7.32E-06	2.58	1.09E-06	7.85E-06	2.49
40%	6.76E-06	7.48E-07	7.51E-06	2.54	1.60E-06	8.36E-06	2.41
45%	6.76E-06	9.51E-07	7.71E-06	2.51	2.21E-06	8.97E-06	2.33
50%	6.76E-06	1.18E-06	7.94E-06	2.47	3.05E-06	9.81E-06	2.23

Table H.33 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 2044 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
10%	6.76E-06	2.50E-11	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
15%	6.76E-06	2.50E-11	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
20%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
25%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
30%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
35%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
40%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
45%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
50%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68

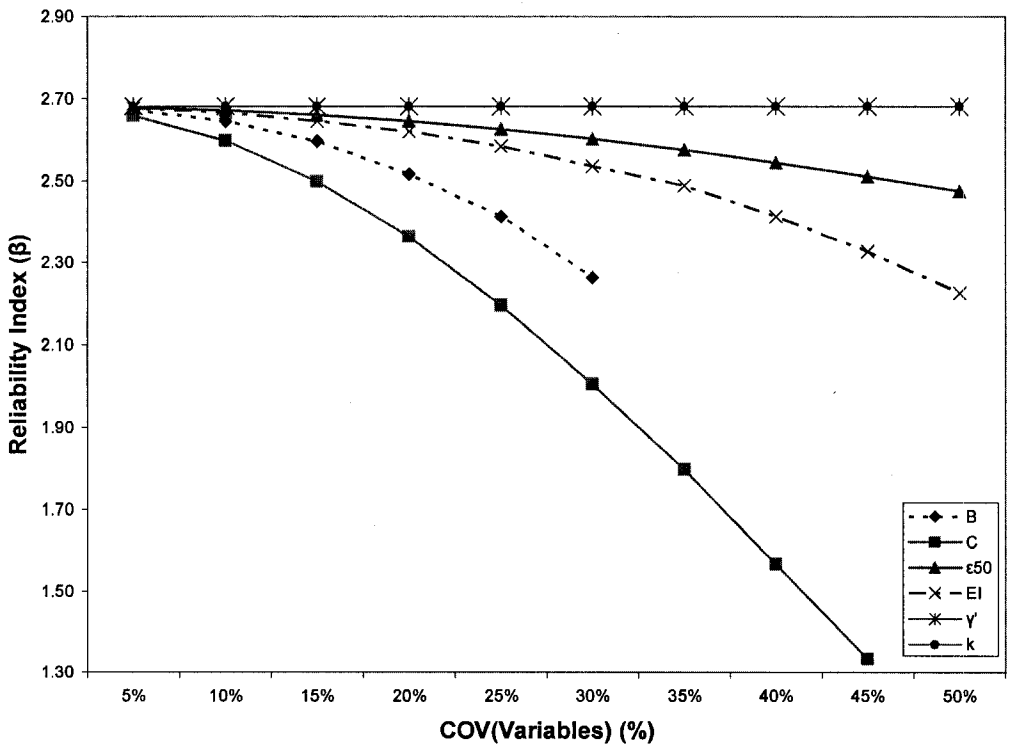

Fig. H.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (3D) at 2044 kN lateral load.

For lateral load 2283 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00563 \text{ m}$$

Table H.34 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 2283 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	9.00E-08	6.85E-06	2.15	1.94E-07	6.95E-06	2.14
10%	6.76E-06	3.72E-07	7.13E-06	2.11	7.66E-07	7.53E-06	2.05
15%	6.76E-06	9.41E-07	7.70E-06	2.03	1.84E-06	8.60E-06	1.92
20%	6.76E-06	1.96E-06	8.72E-06	1.91	3.42E-06	1.02E-05	1.76
25%	6.76E-06	3.72E-06	1.05E-05	1.74	5.86E-06	1.26E-05	1.59
30%	6.76E-06	7.90E-06	1.47E-05	1.47	9.80E-06	1.66E-05	1.38
35%	6.76E-06	Failed	Failed	Failed	1.59E-05	2.26E-05	1.18
40%	6.76E-06	Failed	Failed	Failed	2.69E-05	3.36E-05	0.97
45%	6.76E-06	Failed	Failed	Failed	5.14E-05	5.82E-05	0.74
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table H.35 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'ε_{50}' and 'EI' and applied lateral load 2283 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.32E-08	6.77E-06	2.16	3.14E-08	6.79E-06	2.16
10%	6.76E-06	5.52E-08	6.82E-06	2.16	1.26E-07	6.89E-06	2.15
15%	6.76E-06	1.23E-07	6.88E-06	2.15	2.93E-07	7.05E-06	2.12
20%	6.76E-06	2.21E-07	6.98E-06	2.13	5.42E-07	7.30E-06	2.08
25%	6.76E-06	3.60E-07	7.12E-06	2.11	8.77E-07	7.64E-06	2.04
30%	6.76E-06	5.11E-07	7.27E-06	2.09	1.33E-06	8.09E-06	1.98
35%	6.76E-06	7.14E-07	7.47E-06	2.06	1.88E-06	8.64E-06	1.91
40%	6.76E-06	9.31E-07	7.69E-06	2.03	2.77E-06	9.53E-06	1.82
45%	6.76E-06	1.17E-06	7.93E-06	2.00	3.82E-06	1.06E-05	1.73
50%	6.76E-06	1.40E-06	8.16E-06	1.97	5.37E-06	1.21E-05	1.62

Table H.36 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 2283 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
10%	6.76E-06	0.00E+00	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
15%	6.76E-06	2.50E-11	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
20%	6.76E-06	2.50E-11	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
25%	6.76E-06	1.00E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
30%	6.76E-06	1.00E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
35%	6.76E-06	2.25E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
40%	6.76E-06	2.25E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
45%	6.76E-06	2.25E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
50%	6.76E-06	4.00E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17

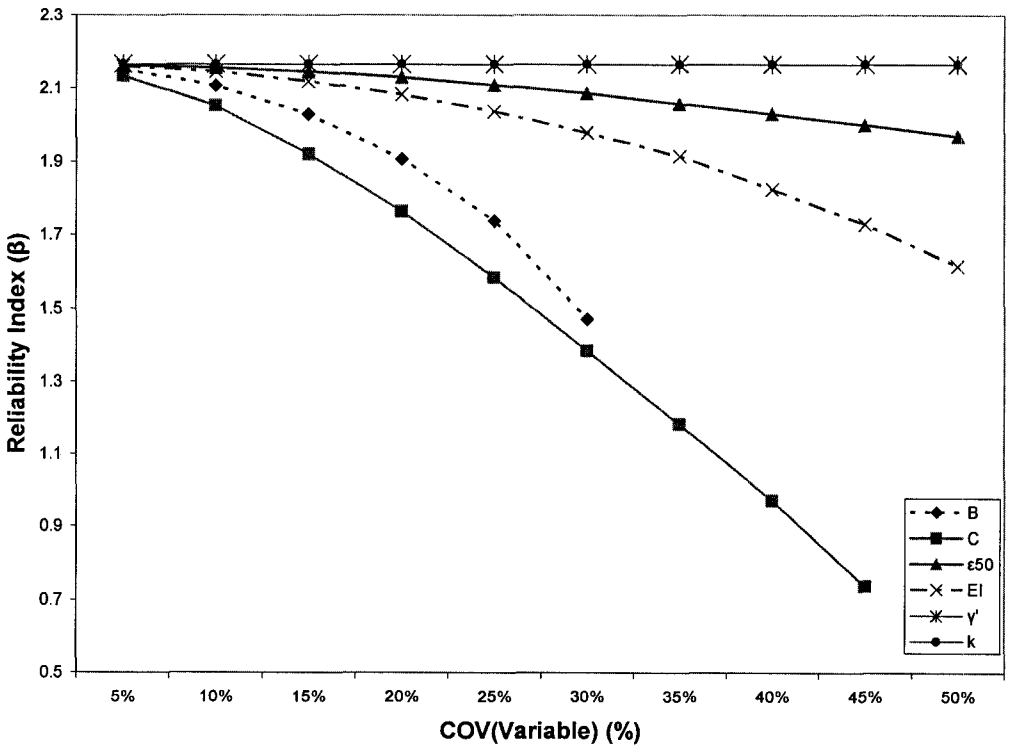

Fig. H.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (3D) at 2283 kN lateral load.

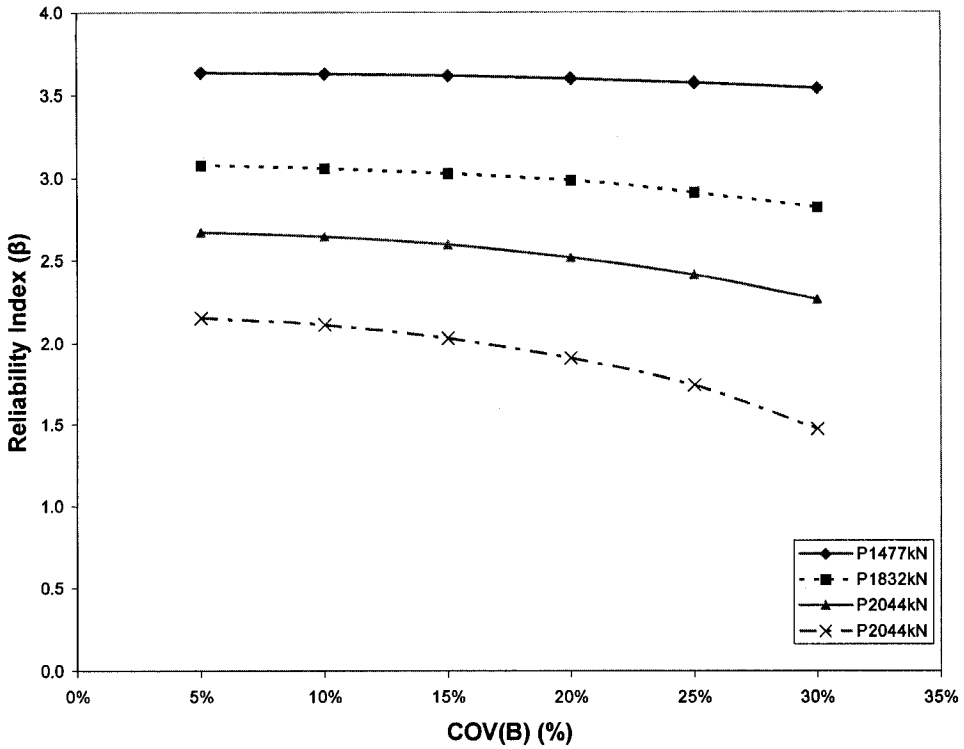

Fig. H.17 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (3D) with varying 'B'.

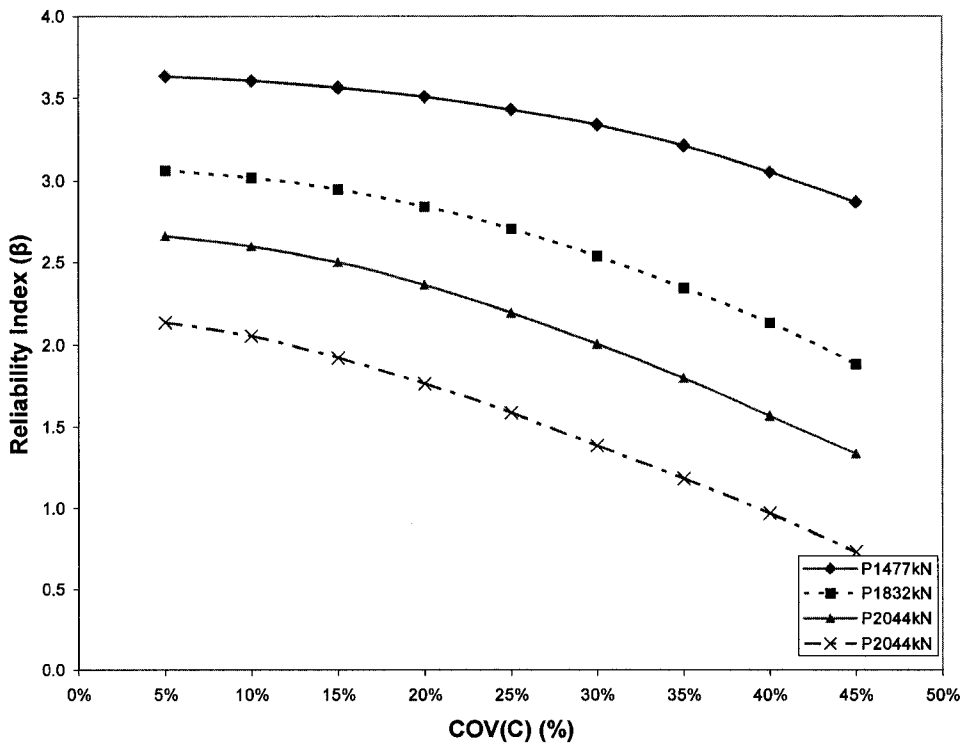

Fig. H.18 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (3D) with varying 'C'.

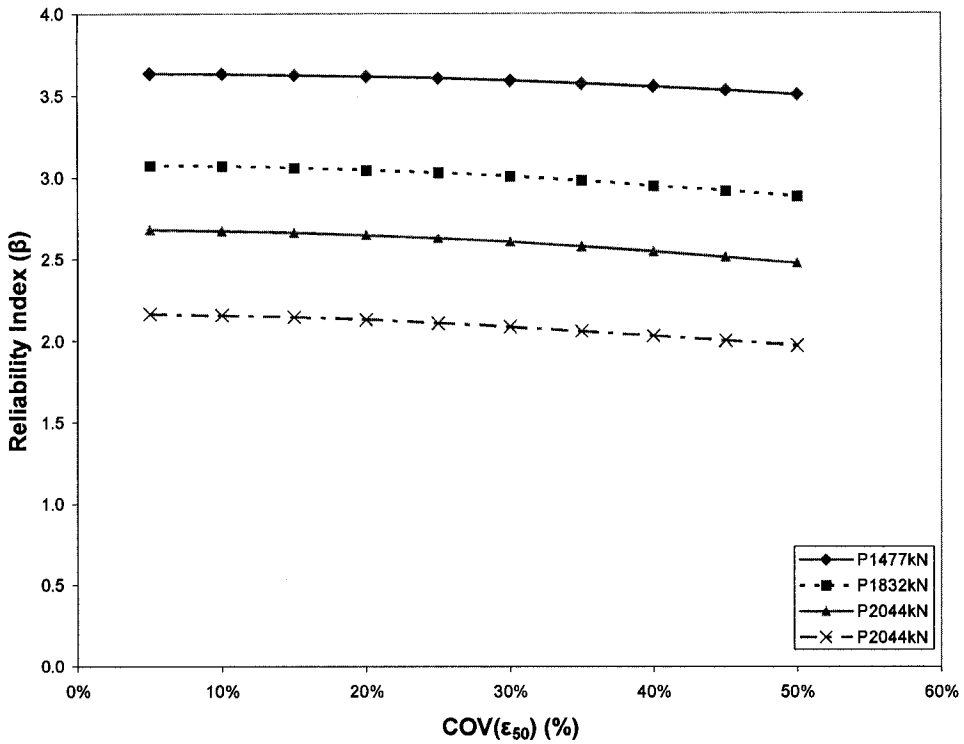

Fig. H.19 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (3D) with varying 'ε_{50}'.

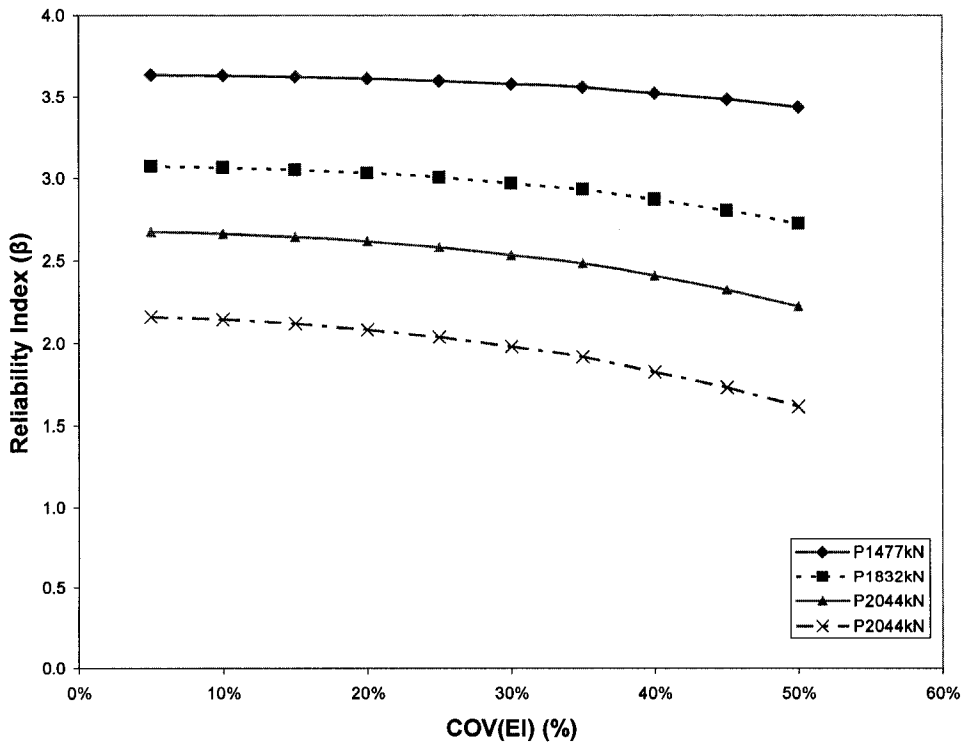

Fig. H.20 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (3D) with varying 'EI'.

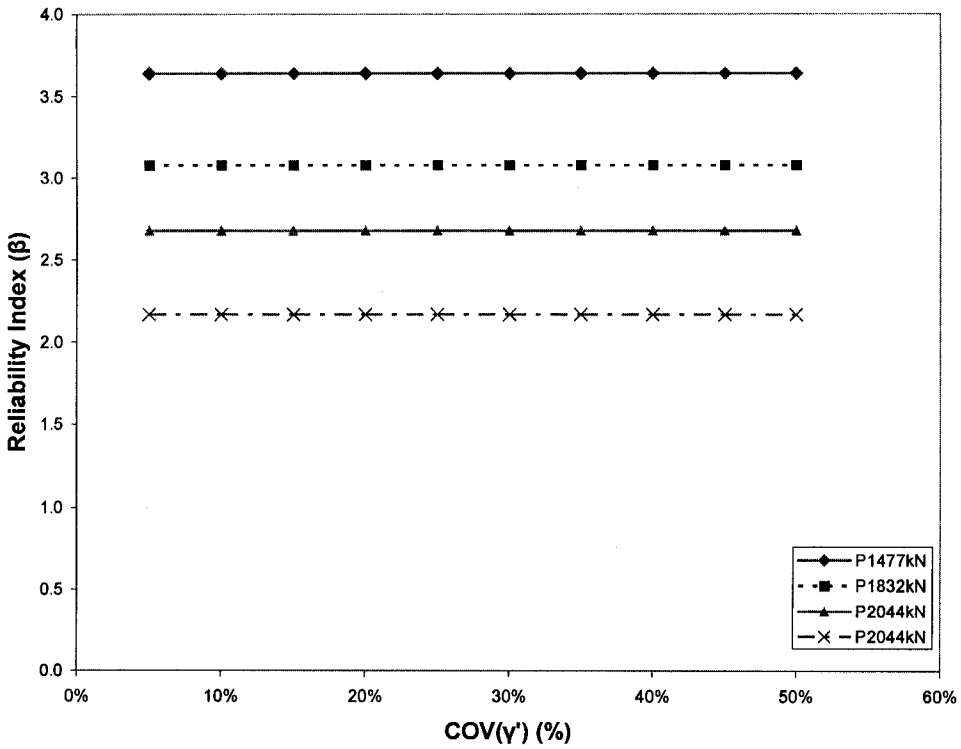

Fig. H.21 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (3D) with varying 'γ''.

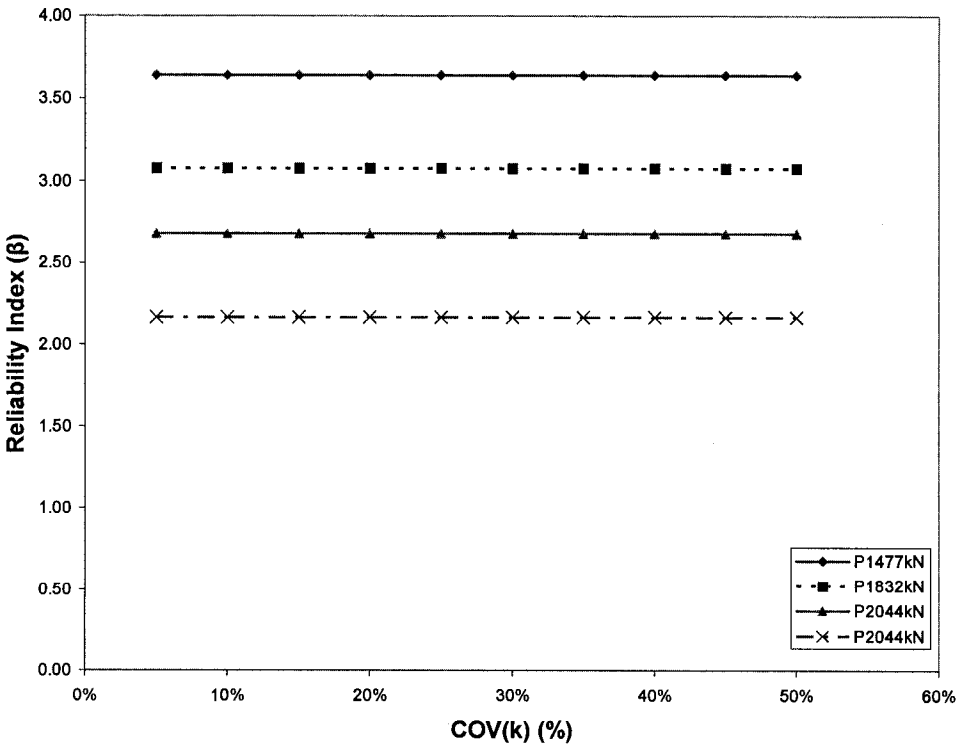

Fig. H.22 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (3D) with varying 'k'.

H.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 1477 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 821.08 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table H.37 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 1477 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) (kN-m)^2	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)
5%	31969.44	0.5476	31969.988	4.59	0.7569	31970.197	4.59
10%	31969.44	2.0164	31971.456	4.59	2.805625	31972.246	4.59
15%	31969.44	4.515625	31973.956	4.59	6.838225	31976.278	4.59
20%	31969.44	8.5849	31978.025	4.59	12.6736	31982.114	4.59
25%	31969.44	6.05284	31975.493	4.59	8.93025	31978.370	4.59
30%	31969.44	Failed	Failed	Failed	34.987225	32004.427	4.59
35%	31969.44	Failed	Failed	Failed	49.8436	32019.284	4.59
40%	31969.44	Failed	Failed	Failed	65.529025	32034.969	4.59
45%	31969.44	Failed	Failed	Failed	79.121025	32048.561	4.59
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table H.38 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying ε_{50} and EI and applied lateral load 1477 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.09	31969.530	4.59	0.3991942	31969.839	4.59
10%	31969.44	0.16	31969.600	4.59	1.3120661	31970.752	4.59
15%	31969.44	0.2304	31969.670	4.59	2.6925826	31972.133	4.59
20%	31969.44	0.36	31969.800	4.59	4.5059711	31973.946	4.59
25%	31969.44	0.13924	31969.579	4.59	2.685124	31972.125	4.59
30%	31969.44	0.390625	31969.831	4.59	9.3025	31978.743	4.59
35%	31969.44	0.416025	31969.856	4.59	10.681012	31980.121	4.59
40%	31969.44	0.540225	31969.980	4.59	15.423471	31984.863	4.59
45%	31969.44	0.697225	31970.137	4.59	19.041322	31988.481	4.59
50%	31969.44	0.81	31970.250	4.59	22.996384	31992.436	4.59

Table H.39 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 1477 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0004	31969.440	4.59	2.5E-05	31969.440	4.59
10%	31969.44	0.0016	31969.442	4.59	0.0001	31969.440	4.59
15%	31969.44	0.0036	31969.444	4.59	0.0004	31969.440	4.59
20%	31969.44	0.0064	31969.446	4.59	0.0009	31969.441	4.59
25%	31969.44	0.004	31969.444	4.59	0.00049	31969.440	4.59
30%	31969.44	0.0144	31969.454	4.59	0.002025	31969.442	4.59
35%	31969.44	0.0196	31969.460	4.59	0.0025	31969.443	4.59
40%	31969.44	0.0256	31969.466	4.59	0.001225	31969.441	4.59
45%	31969.44	0.030625	31969.471	4.59	0.000225	31969.440	4.59
50%	31969.44	0.038025	31969.478	4.59	0.198025	31969.638	4.59

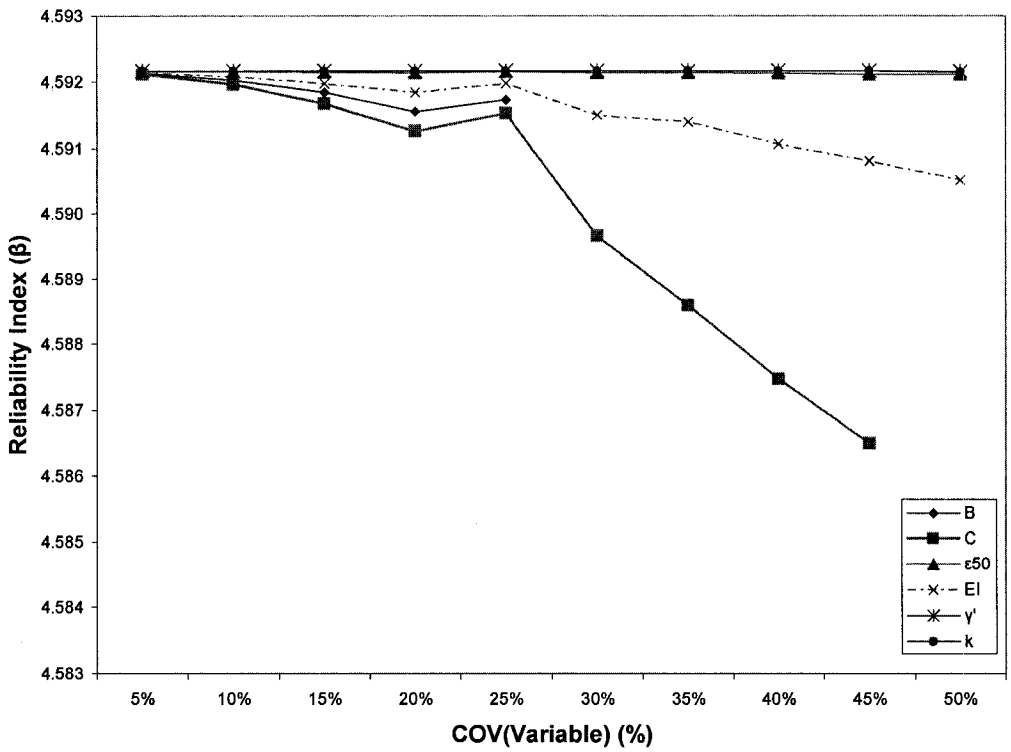

Fig. H.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (3D) at 1477 kN lateral load.

For lateral load 1832 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 795.77 \text{ kN.m}$$

Table H.40 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 1832 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1.44	31970.88	4.45	6.275025	31975.72	4.45
10%	31969.44	6.375625	31975.82	4.45	27.5625	31997.00	4.45
15%	31969.44	16.8921	31986.33	4.45	58.293225	32027.73	4.45
20%	31969.44	34.164025	32003.60	4.45	76.125625	32045.57	4.45
25%	31969.44	62.2521	32031.69	4.45	98.704225	32068.14	4.44
30%	31969.44	Failed	Failed	Failed	121.55063	32090.99	4.44
35%	31969.44	Failed	Failed	Failed	145.6849	32115.12	4.44
40%	31969.44	Failed	Failed	Failed	169	32138.44	4.44
45%	31969.44	Failed	Failed	Failed	190.1641	32159.60	4.44
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table H.41 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying ε_{50} and EI and applied lateral load 1832 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.600625	31970.04	4.45	1.3016736	31970.74	4.45
10%	31969.44	2.387025	31971.83	4.45	4.8600207	31974.30	4.45
15%	31969.44	5.784025	31975.22	4.45	11.252975	31980.69	4.45
20%	31969.44	9.8596	31979.30	4.45	21.83438	31991.27	4.45
25%	31969.44	15.800625	31985.24	4.45	34.488926	32003.93	4.45
30%	31969.44	17.64	31987.08	4.45	49.063657	32018.50	4.45
35%	31969.44	15.800625	31985.24	4.45	51.84	32021.28	4.45
40%	31969.44	13.653025	31983.09	4.45	60.344649	32029.78	4.45
45%	31969.44	11.390625	31980.83	4.45	65.46281	32034.90	4.45
50%	31969.44	9.1809	31978.62	4.45	70.331095	32039.77	4.45

Table H.42 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 1832 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0004	31969.44	4.45	0.000225	31969.44	4.45
10%	31969.44	0.0025	31969.44	4.45	0.0009	31969.44	4.45
15%	31969.44	0.0049	31969.44	4.45	0.0169	31969.46	4.45
20%	31969.44	0.01	31969.45	4.45	0.0196	31969.46	4.45
25%	31969.44	0.0144	31969.45	4.45	0.0256	31969.47	4.45
30%	31969.44	0.0196	31969.46	4.45	0.030625	31969.47	4.45
35%	31969.44	0.027225	31969.47	4.45	0.0324	31969.47	4.45
40%	31969.44	0.0361	31969.48	4.45	0.034225	31969.47	4.45
45%	31969.44	0.0441	31969.48	4.45	0.034225	31969.47	4.45
50%	31969.44	0.0576	31969.50	4.45	13.505625	31982.95	4.45

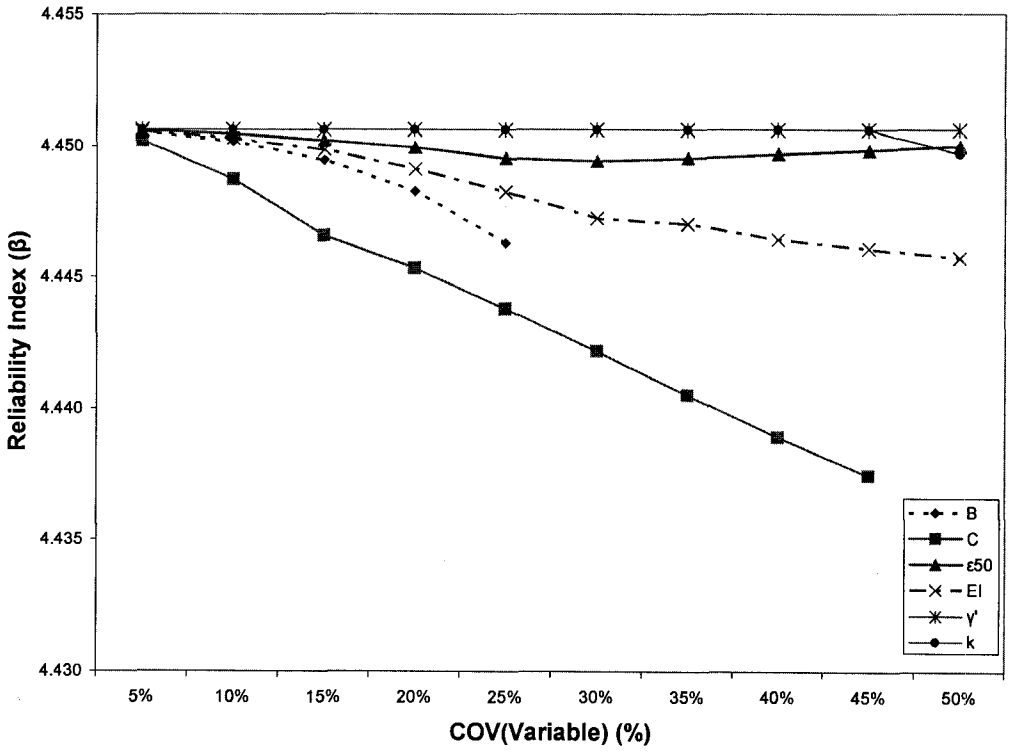

Fig. H.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (3D) at 1832 kN lateral load.

For lateral load 2044 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 779.3 \text{ kN.m}$$

Table H.43 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 2044 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	3.0625	31972.50	4.36	10.24	31979.68	4.36
10%	31969.44	14.44	31983.88	4.36	39.69	32009.13	4.36
15%	31969.44	36	32005.44	4.36	86.49	32055.93	4.35
20%	31969.44	73.96	32043.40	4.35	150.0625	32119.50	4.35
25%	31969.44	132.25	32101.69	4.35	322.5616	32292.00	4.35
30%	31969.44	Failed	Failed	Failed	222.01	32191.45	4.34
35%	31969.44	Failed	Failed	Failed	248.0625	32217.50	4.34
40%	31969.44	Failed	Failed	Failed	262.44	32231.88	4.34
45%	31969.44	Failed	Failed	Failed	422.3025	32391.74	4.33
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table H.44 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying ε_{50} and EI and applied lateral load 2044 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.4225	31969.86	4.36	1.2913223	31970.73	4.36
10%	31969.44	1.8225	31971.26	4.36	5.3739669	31974.81	4.36
15%	31969.44	4.6225	31974.06	4.36	11.933884	31981.37	4.36
20%	31969.44	8.1225	31977.56	4.36	22.347107	31991.79	4.36
25%	31969.44	12.96	31982.40	4.36	34.917355	32004.36	4.36
30%	31969.44	18.49	31987.93	4.36	50.280992	32019.72	4.36
35%	31969.44	25.5025	31994.94	4.36	66.200413	32035.64	4.35
40%	31969.44	34.81	32004.25	4.36	92.859504	32062.30	4.35
45%	31969.44	34.81	32004.25	4.36	120.00207	32089.44	4.35
50%	31969.44	29.16	31998.60	4.36	133.29752	32102.74	4.35

Table H.45 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 2044 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.36	0	31969.44	4.36
10%	31969.44	0.0025	31969.44	4.36	0	31969.44	4.36
15%	31969.44	0.0025	31969.44	4.36	0.0025	31969.44	4.36
20%	31969.44	0.01	31969.45	4.36	0.0025	31969.44	4.36
25%	31969.44	0.0225	31969.46	4.36	0.0025	31969.44	4.36
30%	31969.44	0.0225	31969.46	4.36	0.0025	31969.44	4.36
35%	31969.44	0.0625	31969.50	4.36	0.0025	31969.44	4.36
40%	31969.44	0.0625	31969.50	4.36	0.0025	31969.44	4.36
45%	31969.44	0.0625	31969.50	4.36	0.0025	31969.44	4.36
50%	31969.44	0.09	31969.53	4.36	0.0025	31969.44	4.36

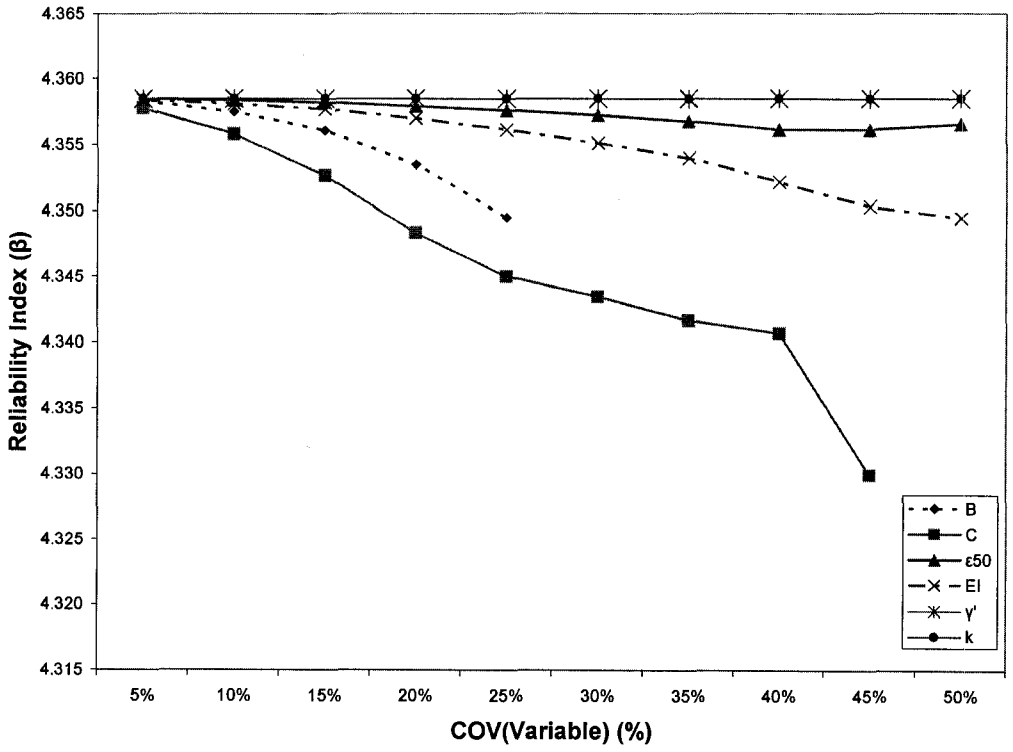

Fig. H.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (3D) at 2044 kN lateral load.

For lateral load 2283 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 758.9 \text{ kN.m}$$

Table H.46 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'B' and 'C' and applied lateral load 2283 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	7.29	31976.73	4.24	14.8225	31984.26	4.24
10%	31969.44	29.7025	31999.14	4.24	53.29	32022.73	4.24
15%	31969.44	75.69	32045.13	4.24	117.7225	32087.16	4.24
20%	31969.44	156.25	32125.69	4.23	198.81	32168.25	4.23
25%	31969.44	Failed	Failed	Failed	301.0225	32270.46	4.22
30%	31969.44	Failed	Failed	Failed	380.25	32349.69	4.22
35%	31969.44	Failed	Failed	Failed	396.01	32365.45	4.22
40%	31969.44	Failed	Failed	Failed	731.7025	32701.14	4.20
45%	31969.44	Failed	Failed	Failed	1413.76	33383.20	4.15
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table H.47 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying ε_{50} and EI and applied lateral load 2283 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.36	31969.800	4.24	1.3966942	31970.837	4.24
10%	31969.44	1.3225	31970.763	4.24	5.5867769	31975.027	4.24
15%	31969.44	2.89	31972.330	4.24	12.570248	31982.010	4.24
20%	31969.44	4.6225	31974.063	4.24	21.919421	31991.359	4.24
25%	31969.44	7.84	31977.280	4.24	33.85124	32003.291	4.24
30%	31969.44	10.24	31979.680	4.24	47.735537	32017.176	4.24
35%	31969.44	13.69	31983.130	4.24	60.415289	32029.855	4.24
40%	31969.44	17.64	31987.080	4.24	84.305785	32053.746	4.24
45%	31969.44	20.7025	31990.143	4.24	107.40496	32076.845	4.24
50%	31969.44	23.04	31992.480	4.24	131.20661	32100.647	4.24

Table H.48 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D), varying 'γ'' and 'k' and applied lateral load 2283 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.24	0.0025	31969.44	4.24
10%	31969.44	0.0025	31969.44	4.24	0.0025	31969.44	4.24
15%	31969.44	0.01	31969.45	4.24	0.0025	31969.44	4.24
20%	31969.44	0.01	31969.45	4.24	0.0025	31969.44	4.24
25%	31969.44	0.0225	31969.46	4.24	0.0025	31969.44	4.24
30%	31969.44	0.0225	31969.46	4.24	0.01	31969.45	4.24
35%	31969.44	0.04	31969.48	4.24	0.01	31969.45	4.24
40%	31969.44	0.04	31969.48	4.24	0.01	31969.45	4.24
45%	31969.44	0.0625	31969.50	4.24	0.01	31969.45	4.24
50%	31969.44	0.0625	31969.50	4.24	0.01	31969.45	4.24

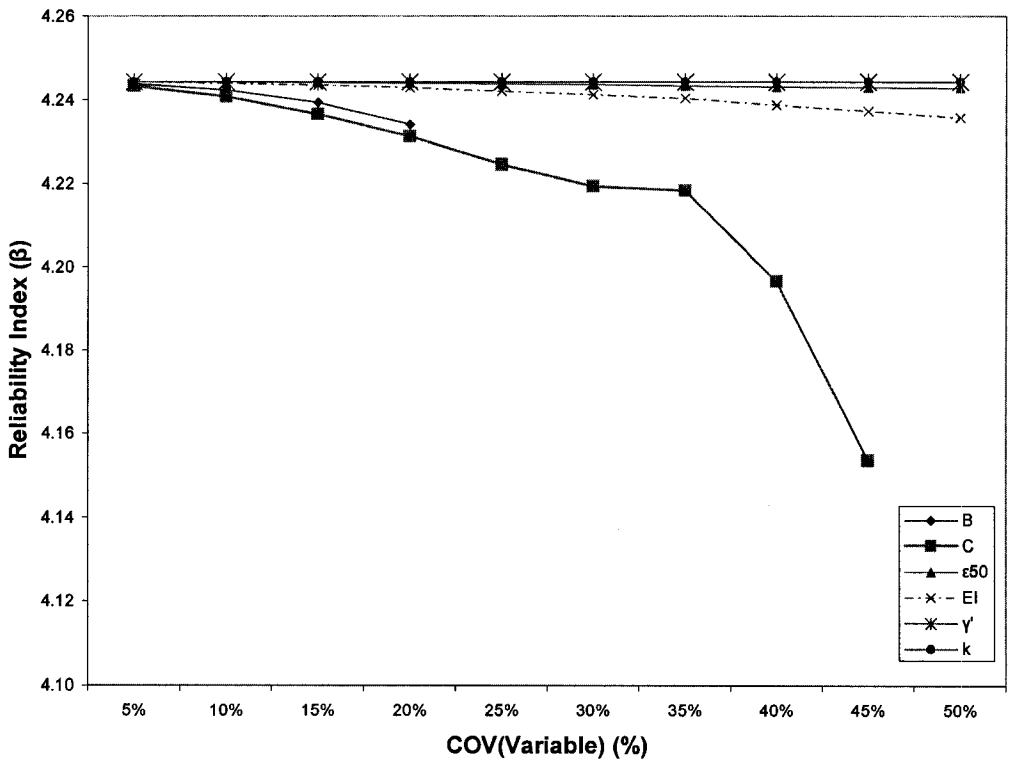

Fig. H.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (3D) at 2283 kN lateral load.

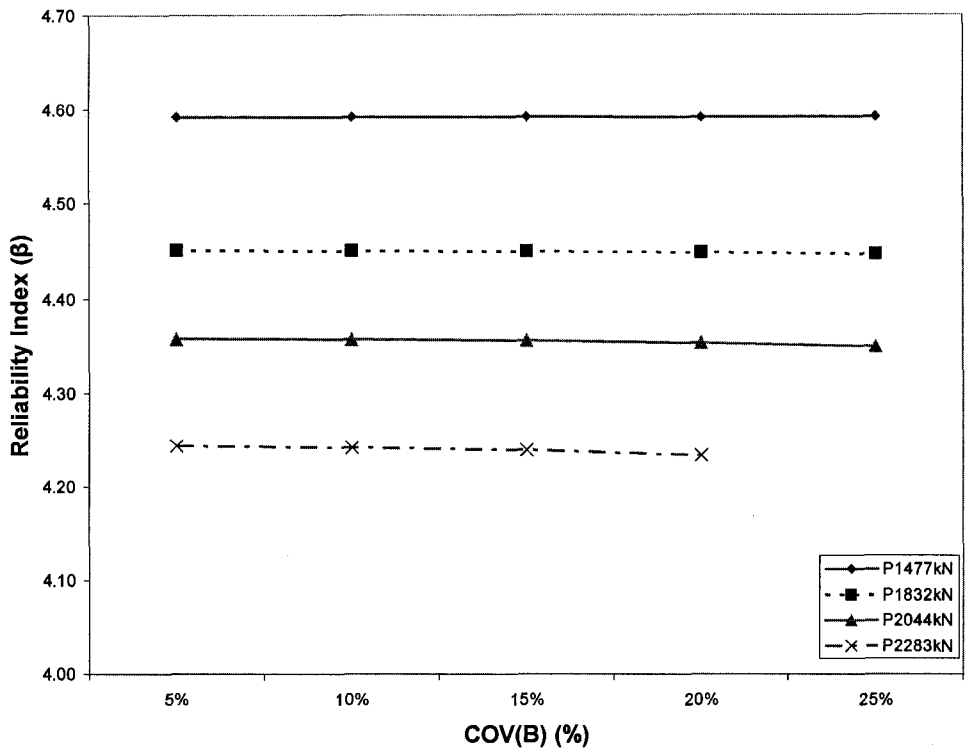

Fig. H.27 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D) with varying 'B'.

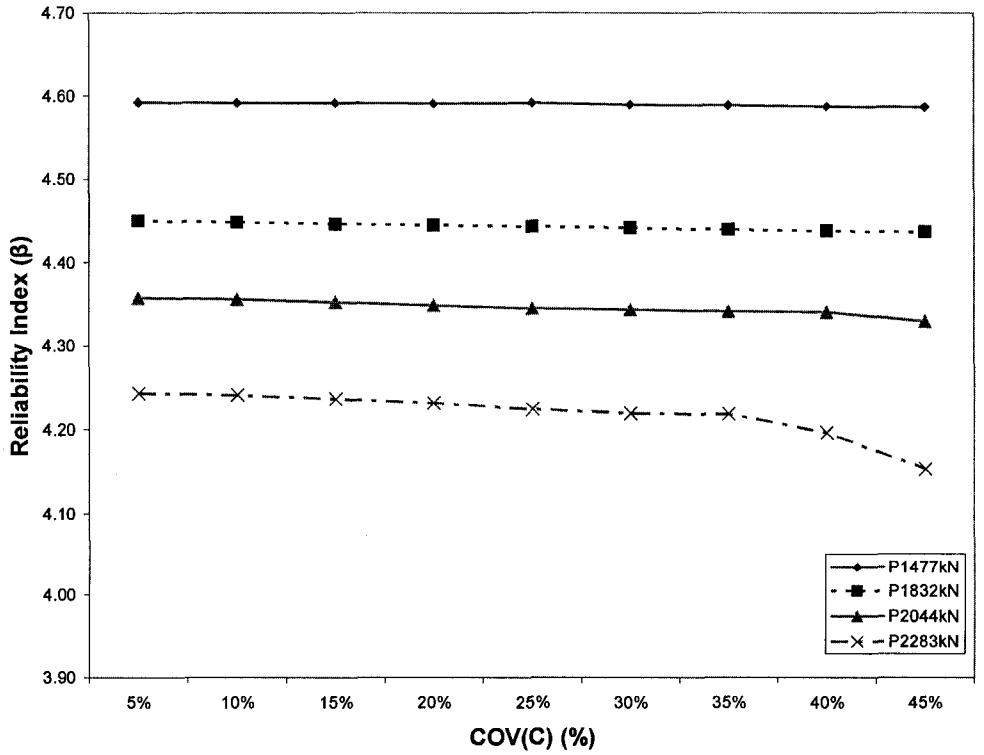

Fig. H.28 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D) with varying 'C'.

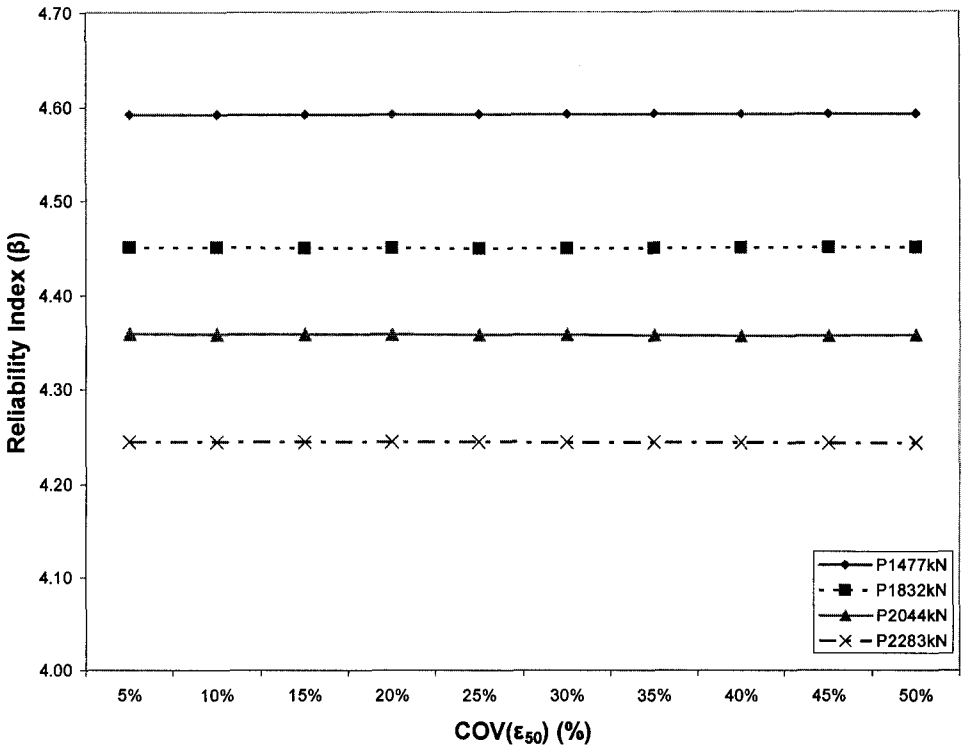

Fig. H.29 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D) with varying 'ε_{50}'.

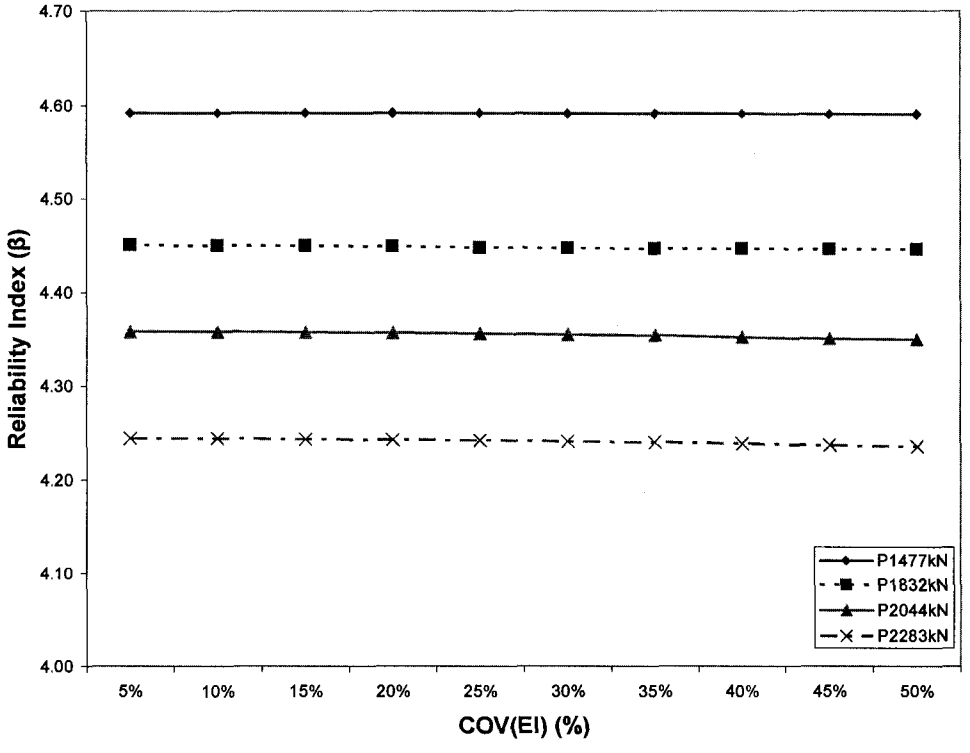

Fig. H.30 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D) with varying 'EI'.

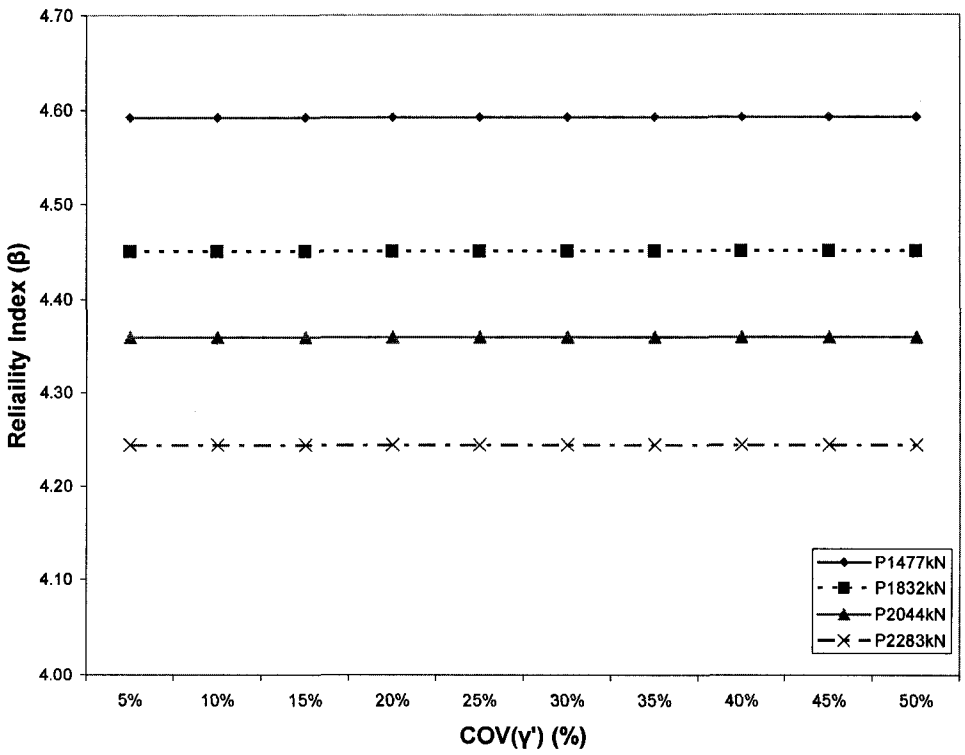

Fig. H.31 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D) with varying 'γ'.

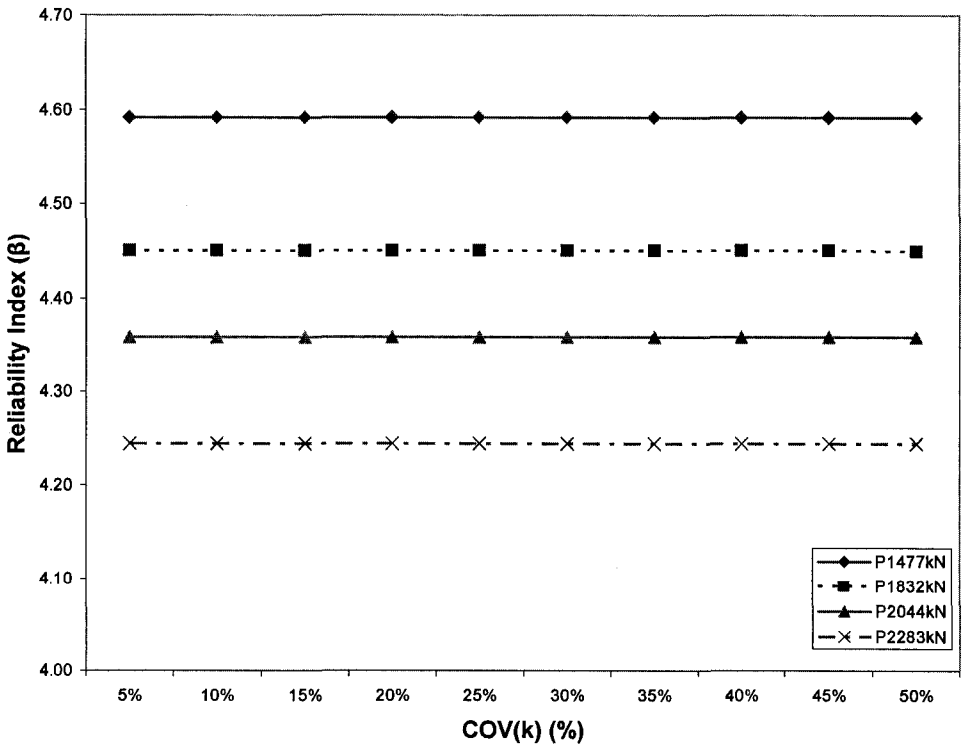

Fig. H.32 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (3D) with varying 'k'.

APPENDIX I

LATERALLY LOADED HINGED HEAD LONG PILE GROUP

(Spacing: 4D)

I.1.1 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (4D) and with 'B' as varying random design variable

Table I.1. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 643 kN and 898 kN.

			P=643 kN (67, 72, 76 kN)				P=898 kN (93, 100, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	0.00352	84.82	91.68	98.13	0.00618	117.7	128	137.8
45%	0.052258	0.2794	0.00335	85.08	91.74	97.83	0.00574	117.9	128	137.6
40%	0.0412902	0.3048	0.00324	85.26	91.71	97.68	0.00538	118.1	128	137.4
35%	0.0316128	0.3302	0.00314	85.37	91.68	97.6	0.00511	118.3	128.1	137.2
30%	0.0232258	0.3556	0.00307	85.39	91.67	97.59	0.0049	118.5	128	137
25%	0.016129	0.381	0.00299	85.44	91.65	97.57	0.00471	118.7	128.1	136.8
20%	0.0103226	0.4064	0.00292	85.45	91.63	97.57	0.00458	119.1	128.1	136.4
15%	0.0058064	0.4318	0.00294	85.47	91.63	97.55	0.00462	119.1	128.1	136.4
10%	0.0025806	0.4572	0.00297	85.49	91.63	97.53	0.00466	119.1	128.1	136.4
5%	0.0006452	0.4826	0.003	85.51	91.63	97.51	0.0047	119.1	128.1	136.3
0%	0	0.508	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5%	0.0006452	0.5334	0.00304	85.54	91.62	97.48	0.00477	119.2	128.1	136.3
10%	0.0025806	0.5588	0.00306	85.56	91.62	97.47	0.0048	119.2	128.1	136.3
15%	0.0058064	0.5842	0.00308	85.57	91.62	97.45	0.00482	119.2	128.1	136.3
20%	0.0103226	0.6096	0.00309	85.59	91.62	97.44	0.00484	119.3	128.1	136.2
25%	0.016129	0.635	0.00311	85.6	91.62	97.42	0.00486	119.3	128.1	136.1
30%	0.0232258	0.6604	0.00312	85.61	91.62	97.41	0.00487	119.4	128.1	136.1
35%	0.0316128	0.6858	0.00313	85.63	91.62	97.39	0.00488	119.4	128.1	136
40%	0.0412902	0.7112	0.00313	85.64	91.62	97.38	0.00489	119.5	128.1	136
45%	0.052258	0.7366	0.00314	85.66	91.62	97.36	0.0049	119.5	128.1	135.9
50%	0.064516	0.762	0.00315	85.67	91.62	97.34	0.0049	119.6	128.1	135.9

Table I.2 Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1055 kN and 1270 kN.

			P=1055 kN (110, 120, 130 kN)				P=1270 kN (130, 140, 150 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	0.00849	141.9	150.4	162.3	0.0153	212.9	225.2	236.1
45%	0.052258	0.2794	0.0077	138.1	150.4	162.1	0.0115	181.8	191.7	200
40%	0.0412902	0.3048	0.00712	138.4	150.4	161.8	0.0102	170.8	181	195.4
35%	0.0316128	0.3302	0.0067	138.6	150.4	161.6	0.00942	166.2	181	195.1
30%	0.0232258	0.3556	0.00635	138.8	150.4	161.5	0.00879	166.5	181.1	194.9
25%	0.016129	0.381	0.00606	138.9	150.4	161.2	0.0083	166.7	181.1	194.6
20%	0.0103226	0.4064	0.00582	139.1	150.4	161.1	0.0079	166.9	181.1	194.4
15%	0.0058064	0.4318	0.00586	139.2	150.4	161	0.00792	167	181.1	194.3
10%	0.0025806	0.4572	0.00589	139.3	150.4	160.9	0.00794	167.1	181.1	194.2
5%	0.0006452	0.4826	0.00592	139.3	150.5	160.9	0.00796	167.2	181.1	194.1
0%	0	0.508	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	0.0006452	0.5334	0.00597	139.5	150.5	160.7	0.00797	167.4	181.1	194
10%	0.0025806	0.5588	0.00599	139.6	150.5	160.5	0.00797	167.5	181.1	193.9
15%	0.0058064	0.5842	0.00601	139.8	150.5	160.4	0.00797	167.6	181.1	193.8
20%	0.0103226	0.6096	0.00603	139.9	150.4	160.3	0.00797	167.7	181.1	193.7
25%	0.016129	0.635	0.00605	139.9	150.4	160.3	0.00796	167.7	181.1	193.6
30%	0.0232258	0.6604	0.00607	139.9	150.4	160.2	0.00796	167.8	181.1	193.5
35%	0.0316128	0.6858	0.00608	140	150.4	160.2	0.00795	167.9	181.1	193.5
40%	0.0412902	0.7112	0.00609	140	150.4	160.2	0.00796	168	181.1	193.4
45%	0.052258	0.7366	0.00609	140.1	150.4	160.1	0.00794	168	181.1	193.3
50%	0.064516	0.762	0.0061	140.1	150.4	160.1	0.00793	168.1	181.1	193.2

Table I.3(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 643 kN and 898 kN.

		P=643 kN		P=898 kN	
COV(B) (%)	Var (B) (m)2	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	6.45E-04	4.00E-10	0.662%	1.22E-09	0.738%
10%	2.58E-03	2.02E-09	1.490%	4.90E-09	1.477%
15%	5.81E-03	4.90E-09	2.318%	1.00E-08	2.110%
20%	1.03E-02	7.23E-09	2.815%	1.69E-08	2.743%
25%	1.61E-02	3.60E-09	1.987%	5.63E-09	1.582%
30%	2.32E-02	6.25E-10	0.828%	2.25E-10	0.316%
35%	3.16E-02	2.50E-11	0.166%	1.32E-08	2.426%
40%	4.13E-02	3.02E-09	1.821%	6.00E-08	5.169%
45%	5.23E-02	1.10E-08	3.477%	1.76E-07	8.861%
50%	6.45E-02	3.42E-08	6.126%	4.10E-07	13.502%

Table I.3(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1055 kN and 1270 kN.

		P=1055 kN		P=1270 kN	
COV(B) (%)	Var (B) (m)2	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	6.45E-04	6.25E-10	0.420%	2.50E-11	0.063%
10%	2.58E-03	2.50E-09	0.840%	2.25E-10	0.188%
15%	5.81E-03	5.63E-09	1.261%	6.25E-10	0.314%
20%	1.03E-02	1.10E-08	1.765%	1.22E-09	0.439%
25%	1.61E-02	2.50E-11	0.084%	2.89E-08	2.133%
30%	2.32E-02	1.96E-08	2.353%	1.72E-07	5.207%
35%	3.16E-02	9.61E-08	5.210%	5.40E-07	9.222%
40%	4.13E-02	2.65E-07	8.655%	1.25E-06	14.053%
45%	5.23E-02	6.48E-07	13.529%	3.17E-06	22.334%
50%	6.45E-02	1.43E-06	20.084%	1.36E-05	46.236%

Table I.4(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 643 kN.

		P=643 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.000225	2.5E-05	0.000225	0.02%	0.01%	0.02%
10%	0.0025806	0.001225	2.5E-05	0.0009	0.04%	0.01%	0.03%
15%	0.0058064	0.0025	2.5E-05	0.0025	0.06%	0.01%	0.05%
20%	0.0103226	0.0049	2.5E-05	0.004225	0.08%	0.01%	0.07%
25%	0.016129	0.0064	0.000225	0.00225	0.09%	0.02%	0.05%
30%	0.0232258	0.0121	0.000625	0.0081	0.13%	0.03%	0.09%
35%	0.0316128	0.0169	0.0009	0.011025	0.15%	0.03%	0.11%
40%	0.0412902	0.0361	0.002025	0.0225	0.22%	0.05%	0.15%
45%	0.052258	0.0841	0.0036	0.055225	0.34%	0.07%	0.24%
50%	0.064516	0.180625	0.0009	0.156025	0.50%	0.03%	0.41%

Table I.4(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 898 kN.

		P=898 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.0025	0	0	0.04%	0.00%	0.00%
10%	0.0025806	0.0025	0	0.0025	0.04%	0.00%	0.04%
15%	0.0058064	0.0025	0	0.0025	0.04%	0.00%	0.04%
20%	0.0103226	0.01	0	0.01	0.08%	0.00%	0.07%
25%	0.016129	0.09	0	0.1225	0.25%	0.00%	0.26%
30%	0.0232258	0.2025	0.0025	0.2025	0.38%	0.04%	0.33%
35%	0.0316128	0.3025	0	0.36	0.46%	0.00%	0.44%
40%	0.0412902	0.49	0.0025	0.49	0.59%	0.04%	0.51%
45%	0.052258	0.64	0.0025	0.7225	0.67%	0.04%	0.62%
50%	0.064516	0.9025	0.0025	0.9025	0.80%	0.04%	0.70%

Table I.4(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1055 kN.

		P=1055 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.01	0	0.01	0.07%	0.00%	0.06%
10%	0.0025806	0.0225	0.0025	0.04	0.11%	0.03%	0.12%
15%	0.0058064	0.09	0.0025	0.09	0.22%	0.03%	0.19%
20%	0.0103226	0.16	0	0.16	0.29%	0.00%	0.25%
25%	0.016129	0.25	0	0.2025	0.36%	0.00%	0.28%
30%	0.0232258	0.3025	0	0.4225	0.39%	0.00%	0.40%
35%	0.0316128	0.49	0	0.49	0.50%	0.00%	0.44%
40%	0.0412902	0.64	0	0.64	0.57%	0.00%	0.50%
45%	0.052258	1	0	1	0.72%	0.00%	0.62%
50%	0.064516	0.81	0	1.21	0.65%	0.00%	0.68%

Table I.4(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1270 kN.

		P=1270 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.01	0	0.0025	0.06%	0.00%	0.03%
10%	0.0025806	0.04	0	0.0225	0.12%	0.00%	0.08%
15%	0.0058064	0.09	0	0.0625	0.18%	0.00%	0.13%
20%	0.0103226	0.16	0	0.1225	0.24%	0.00%	0.18%
25%	0.016129	0.25	0	0.25	0.30%	0.00%	0.26%
30%	0.0232258	0.4225	0	0.49	0.39%	0.00%	0.36%
35%	0.0316128	0.7225	0.0025	0.64	0.51%	0.03%	0.41%
40%	0.0412902	1.96	0.0025	1	0.84%	0.03%	0.52%
45%	0.052258	47.61	28.09	11.2225	4.12%	2.93%	1.73%
50%	0.064516	501.76	486.2025	460.1025	13.39%	12.18%	11.05%

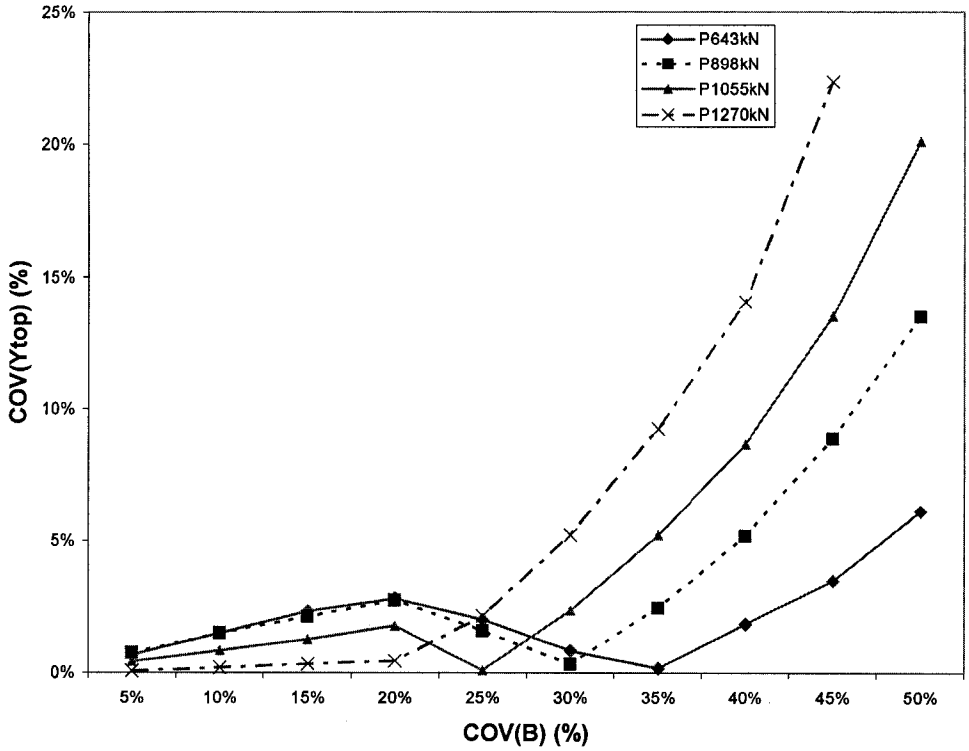

Fig. I.1 COV(Y_{Top}) for varying COV(B) in hinged head long (10T) pile group with spacing (4D).

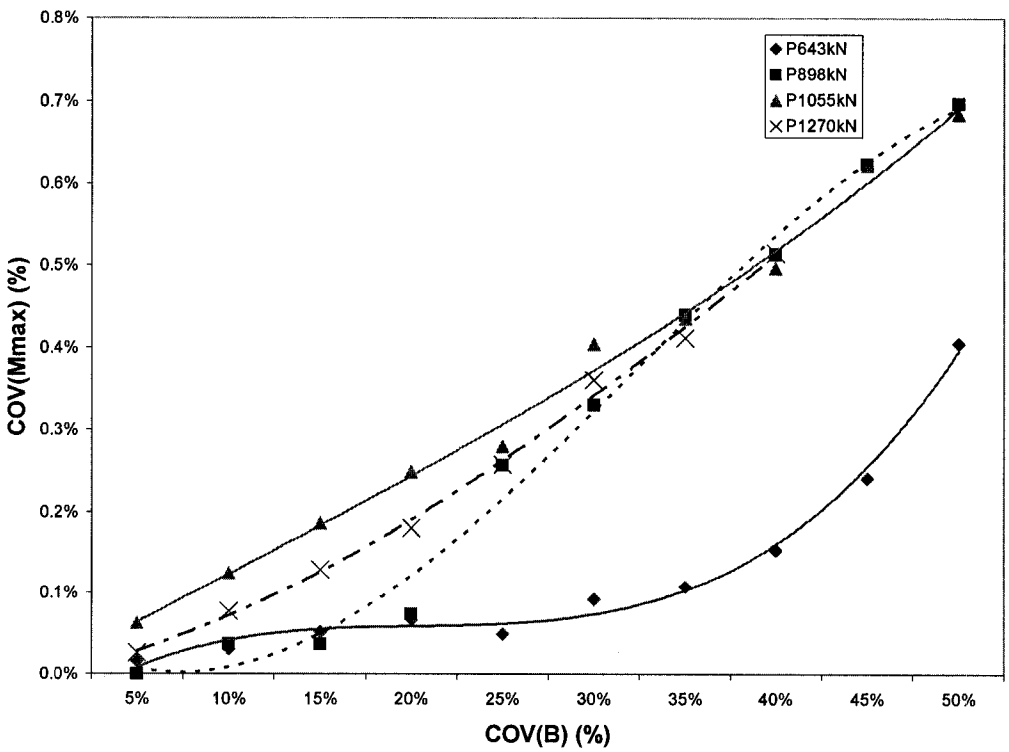

Fig. I.2(a) COV(M_{Max}) for varying COV(B) for pile C in hinged head long pile group with spacing (4D).

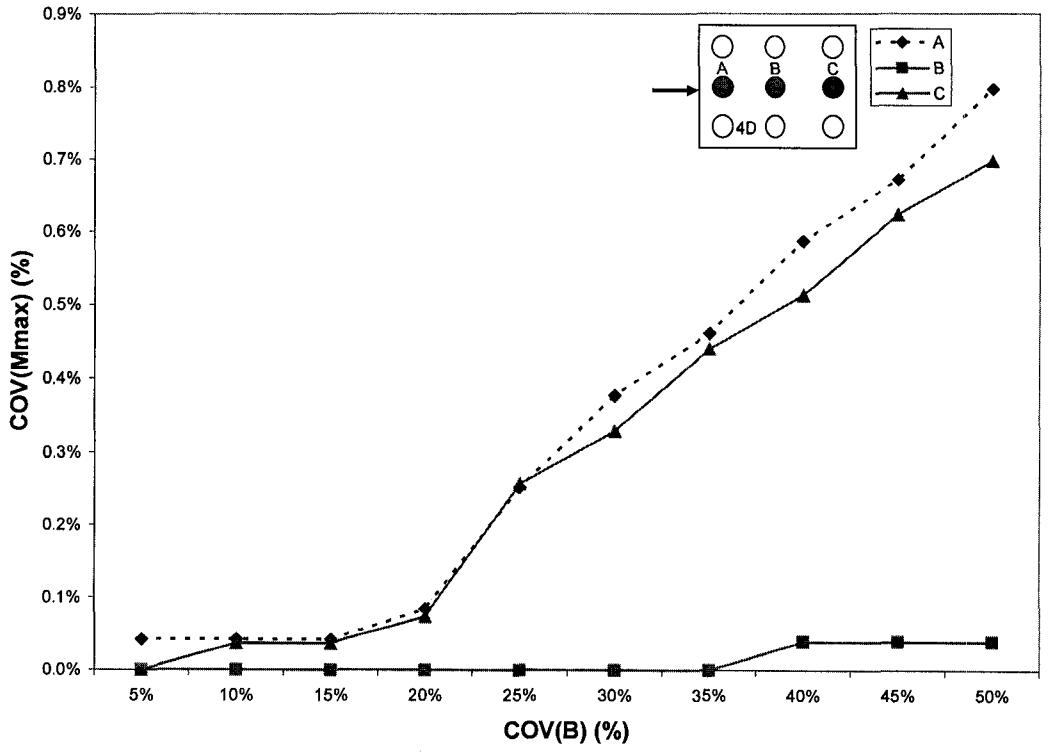

Fig. I.2(b) COV(M_{Max}) for varying COV(B) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (4D) at the optimum lateral load 898 kN.

I.1.2 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (4D) and with 'C' as varying random design variable

Table I.5. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 643 kN and 898 kN.

			P=643 kN (67, 72, 76 kN)				P=898 kN (93, 100, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	0.00519	84.68	91.66	98.47	0.00905	132.3	138.6	144.7
45.00%	1139.0625	41.25	0.00477	84.66	91.7	98.26	0.00818	126.2	132.4	138
40.00%	900	45	0.00443	84.85	91.67	98.11	0.00749	121.4	128	137.7
35.00%	689.0625	48.75	0.00416	84.95	91.67	98.01	0.0069	117.9	128	137.6
30.00%	506.25	52.5	0.00392	85.04	91.67	97.92	0.00641	118.1	128.1	137.4
25.00%	351.5625	56.25	0.00372	85.13	91.67	97.84	0.006	118.2	128.1	137.3
20.00%	225	60	0.00354	85.21	91.67	97.76	0.00565	118.4	128	137.1
15.00%	126.5625	63.75	0.00338	85.31	91.7	97.63	0.00537	118.7	128.1	136.8
10.00%	56.25	67.5	0.00324	85.48	91.68	97.49	0.00513	118.9	128	136.6
5.00%	14.0625	71.25	0.00313	85.53	91.64	97.47	0.00492	119	128	136.5
0.00%	0	75	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5.00%	14.0625	78.75	0.00292	85.49	91.63	97.53	0.00458	119.3	128.1	136.2
10.00%	56.25	82.5	0.00282	85.46	91.63	97.56	0.00443	119.5	128	136.1
15.00%	126.5625	86.25	0.00274	85.45	91.64	97.57	0.00429	119.5	128	136.2
20.00%	225	90	0.00265	85.47	91.65	97.54	0.00417	119.4	128	136.2
25.00%	351.5625	93.75	0.00258	85.48	91.64	97.54	0.00405	119.4	128	136.2
30.00%	506.25	97.5	0.00251	85.48	91.65	97.53	0.00394	119.3	128	136.3
35.00%	689.0625	101.25	0.00243	85.48	91.65	97.53	0.00383	119.3	128	136.3
40.00%	900	105	0.00237	85.49	91.65	97.52	0.00373	119.3	128	136.2
45.00%	1139.0625	108.75	0.00231	85.51	91.65	97.5	0.00364	119.4	128	136.2
50.00%	1406.25	112.5	0.00228	86.13	91.94	96.59	0.00356	119.4	128	136.2

Table I.6. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1055 kN and 1270 kN.

			P=1055 kN (110, 120, 130 kN)				P=1270 kN (130, 140, 150 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	0.0121	166.3	174.7	182.1	0.0178	217.3	231.2	243.6
45.00%	1139.0625	41.25	0.0109	158.3	165.9	173.2	0.0156	207.6	219.4	229.4
40.00%	900	45	0.00989	151.5	158.9	165.7	0.014	199	208.6	217.6
35.00%	689.0625	48.75	0.00906	145.4	152.4	161.8	0.0127	190.1	199.4	208.1
30.00%	506.25	52.5	0.00837	140.2	150.4	161.7	0.0117	182.4	191.3	199.4
25.00%	351.5625	56.25	0.00779	138.6	150.4	161.6	0.0108	175.9	184.2	194.8
20.00%	225	60	0.00732	138.7	150.4	161.5	0.01	169.9	181	194.7
15.00%	126.5625	63.75	0.0069	138.9	150.4	161.3	0.0094	166.8	181	194.5
10.00%	56.25	67.5	0.00654	139	150.4	161.1	0.00885	167	181.1	194.4
5.00%	14.0625	71.25	0.00622	139.2	150.5	161	0.00838	167.2	181.1	194.2
0.00%	0	75	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5.00%	14.0625	78.75	0.00571	139.7	150.5	160.5	0.0076	167.4	181	193.9
10.00%	56.25	82.5	0.00551	140	150.5	160.1	0.00728	167.6	181	193.8
15.00%	126.5625	86.25	0.00534	140.3	150.4	159.9	0.00699	167.8	181.1	193.6
20.00%	225	90	0.00518	140.4	150.3	159.9	0.00675	167.9	181.2	193.3
25.00%	351.5625	93.75	0.00504	140.3	150.3	160	0.00652	168.2	181.2	193
30.00%	506.25	97.5	0.0049	140.3	150.3	160	0.00632	168.6	181	192.8
35.00%	689.0625	101.25	0.00477	140.2	150.3	160.1	0.00615	168.7	181	192.8
40.00%	900	105	0.00465	140.2	150.3	160.1	0.00599	168.8	181	192.7
45.00%	1139.0625	108.75	0.00453	140.2	150.4	160.1	0.00584	168.8	181	192.6
50.00%	1406.25	112.5	0.00442	140.2	150.4	160.1	0.0057	168.8	181	192.7

Table I.7(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 643 kN and 898 kN.

		P=643 kN		P=898 kN	
COV(C) (%)	Var (C) $(kPa)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5.00%	1.41E+01	1.10E-08	3.477%	2.89E-08	3.586%
10.00%	5.63E+01	4.41E-08	6.954%	1.23E-07	7.384%
15.00%	1.27E+02	1.02E-07	10.596%	2.92E-07	11.392%
20.00%	2.25E+02	1.98E-07	14.735%	5.48E-07	15.612%
25.00%	3.52E+02	3.25E-07	18.874%	9.51E-07	20.570%
30.00%	5.06E+02	4.97E-07	23.344%	1.53E-06	26.055%
35.00%	6.89E+02	7.48E-07	28.642%	2.36E-06	32.384%
40.00%	9.00E+02	1.06E-06	34.106%	3.53E-06	39.662%
45.00%	1.14E+03	1.51E-06	40.728%	5.15E-06	47.890%
50.00%	1.41E+03	2.12E-06	48.179%	7.54E-06	57.911%

Table I.7(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1055 kN and 1270 kN.

		P=1055 kN		P=1270 kN	
COV(C) (%)	Var (C) $(kPa)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5.00%	1.41E+01	6.50E-08	4.286%	1.52E-07	4.893%
10.00%	5.63E+01	2.65E-07	8.655%	6.16E-07	9.849%
15.00%	1.27E+02	6.08E-07	13.109%	1.45E-06	15.119%
20.00%	2.25E+02	1.14E-06	17.983%	2.64E-06	20.389%
25.00%	3.52E+02	1.89E-06	23.109%	4.58E-06	26.851%
30.00%	5.06E+02	3.01E-06	29.160%	7.24E-06	33.752%
35.00%	6.89E+02	4.60E-06	36.050%	1.07E-05	41.092%
40.00%	9.00E+02	6.86E-06	44.034%	1.60E-05	50.251%
45.00%	1.14E+03	1.01E-05	53.529%	2.38E-05	61.230%
50.00%	1.41E+03	1.47E-05	64.538%	3.66E-05	75.910%

Table I.8(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 643 kN.

		P=643 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.0004	2.5E-05	0.0009	0.02%	0.01%	0.03%
10.00%	56.25	0.0001	0.000625	0.001225	0.01%	0.03%	0.04%
15.00%	126.5625	0.0049	0.0009	0.0009	0.08%	0.03%	0.03%
20.00%	225	0.0169	1E-04	0.0121	0.15%	0.01%	0.11%
25.00%	351.5625	0.030625	0.000225	0.009	0.20%	0.02%	0.10%
30.00%	506.25	0.0484	1E-04	0.038025	0.26%	0.01%	0.20%
35.00%	689.0625	0.070225	1E-04	0.0576	0.31%	0.01%	0.25%
40.00%	900	0.1024	1E-04	0.087025	0.37%	0.01%	0.30%
45.00%	1139.0625	0.180625	0.000625	0.1444	0.50%	0.03%	0.39%
50.00%	1406.25	0.525625	0.0196	0.8836	0.85%	0.15%	0.96%

Table I.8(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 898 kN.

		P=898 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.0225	0.0025	0.0225	0.13%	0.04%	0.11%
10.00%	56.25	0.09	0	0.0625	0.25%	0.00%	0.18%
15.00%	126.5625	0.16	0.0025	0.09	0.34%	0.04%	0.22%
20.00%	225	0.25	0	0.2025	0.42%	0.00%	0.33%
25.00%	351.5625	0.36	0.0025	0.3025	0.50%	0.04%	0.40%
30.00%	506.25	0.36	0.0025	0.3025	0.50%	0.04%	0.40%
35.00%	689.0625	0.49	0	0.4225	0.59%	0.00%	0.48%
40.00%	900	1.1025	0	0.5625	0.88%	0.00%	0.55%
45.00%	1139.0625	11.56	4.84	0.81	2.85%	1.72%	0.66%
50.00%	1406.25	41.6025	28.09	18.0625	5.41%	4.14%	3.12%

Table I.8(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1055 kN.

		P=1055 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.0625	0	0.0625	0.18%	0.00%	0.16%
10.00%	56.25	0.25	0.0025	0.25	0.36%	0.03%	0.31%
15.00%	126.5625	0.49	0	0.49	0.50%	0.00%	0.44%
20.00%	225	0.7225	0.0025	0.64	0.61%	0.03%	0.50%
25.00%	351.5625	0.7225	0.0025	0.64	0.61%	0.03%	0.50%
30.00%	506.25	0.0025	0.0025	0.7225	0.04%	0.03%	0.53%
35.00%	689.0625	6.76	1.1025	0.7225	1.87%	0.70%	0.53%
40.00%	900	31.9225	18.49	7.84	4.05%	2.86%	1.74%
45.00%	1139.0625	81.9025	60.0625	42.9025	6.49%	5.15%	4.07%
50.00%	1406.25	170.3025	147.6225	121	9.36%	8.07%	6.84%

Table I.8(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1270 kN.

		P=1270 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.01	0.0025	0.0225	0.06%	0.03%	0.08%
10.00%	56.25	0.09	0.0025	0.09	0.18%	0.03%	0.15%
15.00%	126.5625	0.25	0.0025	0.2025	0.30%	0.03%	0.23%
20.00%	225	1	0.01	0.49	0.60%	0.06%	0.36%
25.00%	351.5625	14.8225	2.25	0.81	2.30%	0.83%	0.46%
30.00%	506.25	47.61	26.5225	10.89	4.12%	2.84%	1.70%
35.00%	689.0625	114.49	84.64	58.5225	6.40%	5.08%	3.94%
40.00%	900	228.01	190.44	155.0025	9.03%	7.62%	6.41%
45.00%	1139.0625	376.36	368.64	338.56	11.60%	10.60%	9.48%
50.00%	1406.25	588.0625	630.01	647.7025	14.49%	13.86%	13.11%

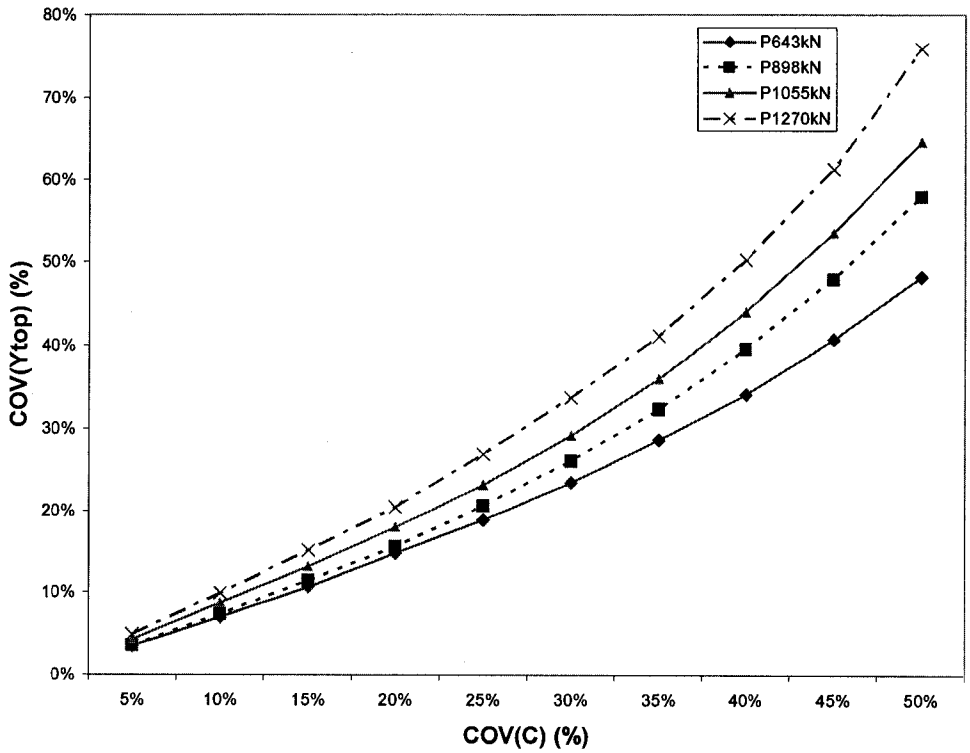

Fig. I.3 COV(Y_{Top}) for varying COV(C) in hinged head long (10T) pile group with spacing (4D).

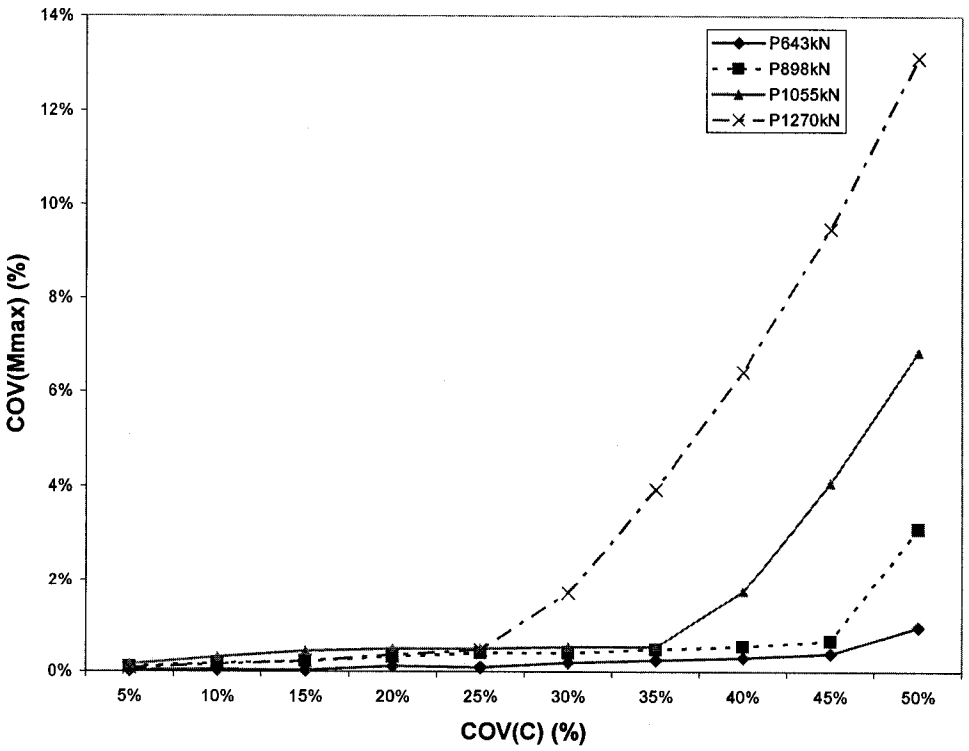

Fig. I.4(a) COV(M_{Max}) for varying COV(C) for pile C in hinged head long pile group with spacing (4D).

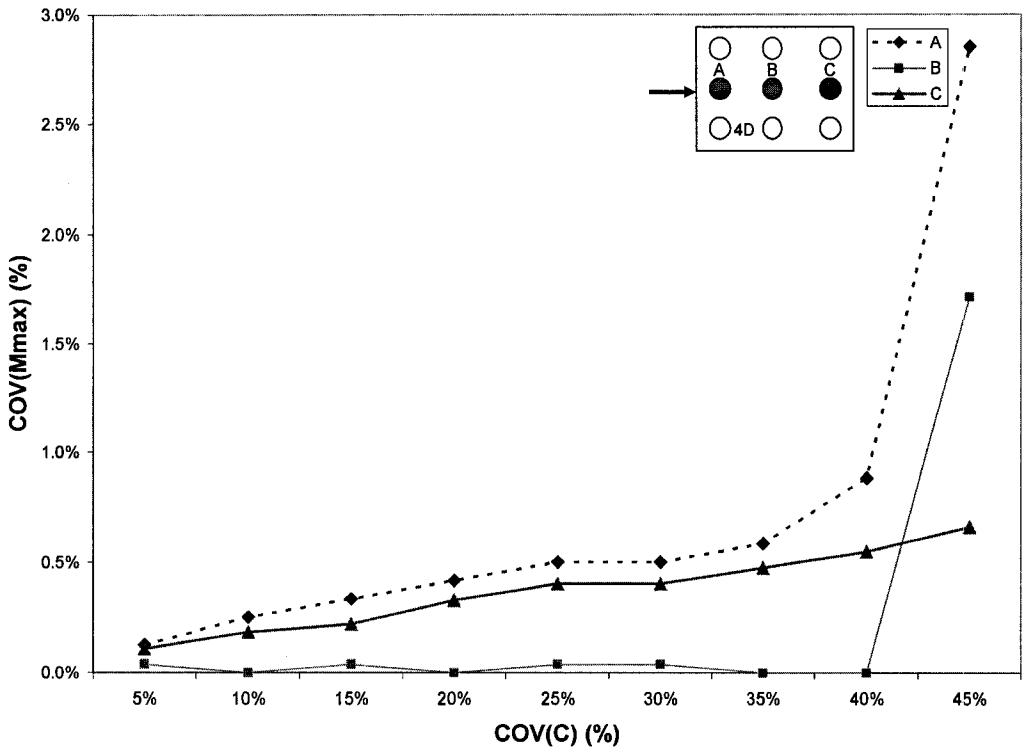

Fig. I.4(b) COV(M_{Max}) for varying COV(C) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (4D) at the optimum lateral load 898 kN.

I.1.3 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (4D) and with 'ε_{50}' as varying random design variable

Table I.9. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 643 kN and 898 kN.

			P=643 kN (67, 72, 76 kN)				P=898 kN (93, 100, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00235	85.5	91.65	97.51	0.00373	119	128	136.6
45%	9.9225E-06	0.00385	0.00243	85.48	91.65	97.53	0.00385	119	128	136.6
40%	0.00000784	0.0042	0.00251	85.47	91.65	97.54	0.00396	119.1	128	136.5
35%	6.0025E-06	0.00455	0.00258	85.47	91.64	97.55	0.00408	119.2	128	136.4
30%	0.00000441	0.0049	0.00265	85.46	91.65	97.55	0.00418	119.4	128	136.2
25%	3.0625E-06	0.00525	0.00273	85.45	91.64	97.57	0.00428	119.5	128	136.1
20%	0.00000196	0.0056	0.00279	85.46	91.63	97.56	0.00438	119.5	128	136.1
15%	1.1025E-06	0.00595	0.00285	85.47	91.63	97.55	0.00447	119.5	128	136.1
10%	0.00000049	0.0063	0.00291	85.49	91.63	97.54	0.00456	119.3	128.1	136.2
5%	1.225E-07	0.00665	0.00297	85.51	91.63	97.52	0.00466	119.2	128.1	136.3
0%	0	0.007	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5%	1.225E-07	0.00735	0.00307	85.55	91.62	97.48	0.00483	119.1	128	136.5
10%	0.00000049	0.0077	0.00312	85.54	91.64	97.47	0.00491	119	128	136.5
15%	1.1025E-06	0.00805	0.00317	85.51	91.66	97.47	0.00499	119	128	136.6
20%	0.00000196	0.0084	0.00321	85.52	91.65	97.47	0.00508	118.9	128	136.6
25%	3.0625E-06	0.00875	0.00326	85.46	91.69	97.49	0.00517	118.9	128	136.6
30%	0.00000441	0.0091	0.00331	85.39	91.72	97.53	0.00525	118.9	128	136.7
35%	6.0025E-06	0.00945	0.00335	85.34	91.72	97.58	0.00532	118.8	128	136.7
40%	0.00000784	0.0098	0.0034	85.3	91.7	97.65	0.0054	118.8	128	136.7
45%	9.9225E-06	0.01015	0.00344	85.26	91.68	97.7	0.00548	118.8	128	136.7
50%	0.00001225	0.0105	0.00349	85.23	91.67	97.74	0.00555	118.7	128	136.8

Table I.10. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1055 kN and 1270 kN.

			P=1055 kN (110, 120, 130 kN)				P=1270 kN (130, 140, 150 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00479	139.6	150.3	160.7	0.00648	168.3	180.9	193.2
45%	9.9225E-06	0.00385	0.00492	139.7	150.3	160.6	0.00663	168.1	181.1	193.2
40%	0.00000784	0.0042	0.00506	139.8	150.4	160.5	0.00679	167.8	181.3	193.3
35%	6.0025E-06	0.00455	0.00518	139.9	150.3	160.4	0.00694	167.7	181.1	193.6
30%	0.00000441	0.0049	0.00528	140	150.3	160.3	0.00709	167.5	181.1	193.8
25%	3.0625E-06	0.00525	0.00539	139.8	150.4	160.3	0.00724	167.5	181.1	193.9
20%	0.00000196	0.0056	0.00551	139.6	150.6	160.5	0.00741	167.5	181.1	193.9
15%	1.1025E-06	0.00595	0.00562	139.5	150.5	160.7	0.00755	167.4	181.1	193.9
10%	0.00000049	0.0063	0.00573	139.4	150.5	160.8	0.00769	167.4	181.1	194
5%	1.225E-07	0.00665	0.00584	139.4	150.5	160.8	0.00783	167.3	181.1	194
0%	0	0.007	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	1.225E-07	0.00735	0.00605	139.3	150.5	160.8	0.0081	167.3	181.1	194.1
10%	0.00000049	0.0077	0.00616	139.3	150.5	160.8	0.00823	167.3	181.1	194.1
15%	1.1025E-06	0.00805	0.00626	139.4	150.5	160.7	0.00836	167.2	181.1	194.1
20%	0.00000196	0.0084	0.00636	139.4	150.5	160.7	0.00848	167.2	181.1	194.2
25%	3.0625E-06	0.00875	0.00646	139.4	150.5	160.7	0.00863	167.2	181.1	194.2
30%	0.00000441	0.0091	0.00656	139.4	150.4	160.7	0.00875	167.1	181.1	194.2
35%	6.0025E-06	0.00945	0.00666	139.4	150.4	160.8	0.00887	167.1	181.1	194.3
40%	0.00000784	0.0098	0.00676	139.4	150.4	160.8	0.00898	167.1	181.1	194.3
45%	9.9225E-06	0.01015	0.00687	139.3	150.4	160.8	0.0091	167	181.1	194.3
50%	0.00001225	0.0105	0.00696	139.3	150.4	160.9	0.00921	167	181.1	194.3

Table I.11(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 643 kN and 898 kN.

		P=643 kN		P=898 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	2.50E-09	1.656%	7.22E-09	1.793%
10%	4.90E-07	1.10E-08	3.477%	3.06E-08	3.692%
15%	1.10E-06	2.56E-08	5.298%	6.76E-08	5.485%
20%	1.96E-06	4.41E-08	6.954%	1.23E-07	7.384%
25%	3.06E-06	7.02E-08	8.775%	1.98E-07	9.388%
30%	4.41E-06	1.09E-07	10.927%	2.86E-07	11.287%
35%	6.00E-06	1.48E-07	12.748%	3.84E-07	13.080%
40%	7.84E-06	1.98E-07	14.735%	5.18E-07	15.190%
45%	9.92E-06	2.55E-07	16.722%	6.64E-07	17.194%
50%	1.23E-05	3.25E-07	18.874%	8.28E-07	19.198%

Table I.11(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1055 kN and 1270 kN.

		P=1055 kN		P=1270 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	1.10E-08	1.765%	1.82E-08	1.694%
10%	4.90E-07	4.62E-08	3.613%	7.29E-08	3.388%
15%	1.10E-06	1.02E-07	5.378%	1.64E-07	5.082%
20%	1.96E-06	1.81E-07	7.143%	2.86E-07	6.713%
25%	3.06E-06	2.86E-07	8.992%	4.83E-07	8.720%
30%	4.41E-06	4.10E-07	10.756%	6.89E-07	10.414%
35%	6.00E-06	5.48E-07	12.437%	9.31E-07	12.108%
40%	7.84E-06	7.23E-07	14.286%	1.20E-06	13.739%
45%	9.92E-06	9.51E-07	16.387%	1.53E-06	15.496%
50%	1.23E-05	1.18E-06	18.235%	1.86E-06	17.127%

Table I.12(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 643 kN.

		P=643 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0004	2.5E-05	0.0004	0.02%	0.01%	0.02%
10%	4.90E-07	0.000625	2.5E-05	0.001225	0.03%	0.01%	0.04%
15%	1.10E-06	0.0004	0.000225	0.0016	0.02%	0.02%	0.04%
20%	1.96E-06	0.0009	0.0001	0.002025	0.04%	0.01%	0.05%
25%	3.06E-06	2.5E-05	0.000625	0.00064	0.01%	0.03%	0.03%
30%	4.41E-06	0.001225	0.001225	1E-04	0.04%	0.04%	0.01%
35%	6.00E-06	0.004225	0.0016	0.000225	0.08%	0.04%	0.02%
40%	7.84E-06	0.007225	0.000625	0.003025	0.10%	0.03%	0.06%
45%	9.92E-06	0.0121	0.000225	0.007225	0.13%	0.02%	0.09%
50%	1.23E-05	0.018225	1E-04	0.013225	0.16%	0.01%	0.12%

Table I.12(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 898 kN.

		P=898 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0025	0.0025	0.01	0.04%	0.04%	0.07%
10%	4.90E-07	0.0225	0.0025	0.0225	0.13%	0.04%	0.11%
15%	1.10E-06	0.0625	0	0.0625	0.21%	0.00%	0.18%
20%	1.96E-06	0.09	0	0.0625	0.25%	0.00%	0.18%
25%	3.06E-06	0.09	0	0.0625	0.25%	0.00%	0.18%
30%	4.41E-06	0.0625	0	0.0625	0.21%	0.00%	0.18%
35%	6.00E-06	0.04	0	0.0225	0.17%	0.00%	0.11%
40%	7.84E-06	0.0225	0	0.01	0.13%	0.00%	0.07%
45%	9.92E-06	0.01	0	0.0025	0.08%	0.00%	0.04%
50%	1.23E-05	0.0225	0	0.01	0.13%	0.00%	0.07%

Table I.12(c) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1055 kN.

		P=1055 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0025	0	0	0.04%	0.00%	0.00%
10%	4.90E-07	0.0025	0	0	0.04%	0.00%	0.00%
15%	1.10E-06	0.0025	0	0	0.04%	0.00%	0.00%
20%	1.96E-06	0.01	0.0025	0.01	0.07%	0.03%	0.06%
25%	3.06E-06	0.04	0.0025	0.04	0.14%	0.03%	0.12%
30%	4.41E-06	0.09	0.0025	0.04	0.22%	0.03%	0.12%
35%	6.00E-06	0.0625	0.0025	0.04	0.18%	0.03%	0.12%
40%	7.84E-06	0.04	0	0.0225	0.14%	0.00%	0.09%
45%	9.92E-06	0.04	0.0025	0.01	0.14%	0.03%	0.06%
50%	1.23E-05	0.0225	0.0025	0.01	0.11%	0.03%	0.06%

Table I.12(d) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1270 kN.

		P=1270 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0	0	0.0025	0.00%	0.00%	0.03%
10%	4.90E-07	0.0025	0	0.0025	0.03%	0.00%	0.03%
15%	1.10E-06	0.01	0	0.01	0.06%	0.00%	0.05%
20%	1.96E-06	0.0225	0	0.0225	0.09%	0.00%	0.08%
25%	3.06E-06	0.0225	0	0.0225	0.09%	0.00%	0.08%
30%	4.41E-06	0.04	0	0.04	0.12%	0.00%	0.10%
35%	6.00E-06	0.09	0	0.1225	0.18%	0.00%	0.18%
40%	7.84E-06	0.1225	0.01	0.25	0.21%	0.06%	0.26%
45%	9.92E-06	0.3025	0	0.3025	0.33%	0.00%	0.28%
50%	1.23E-05	0.4225	0.01	0.3025	0.39%	0.06%	0.28%

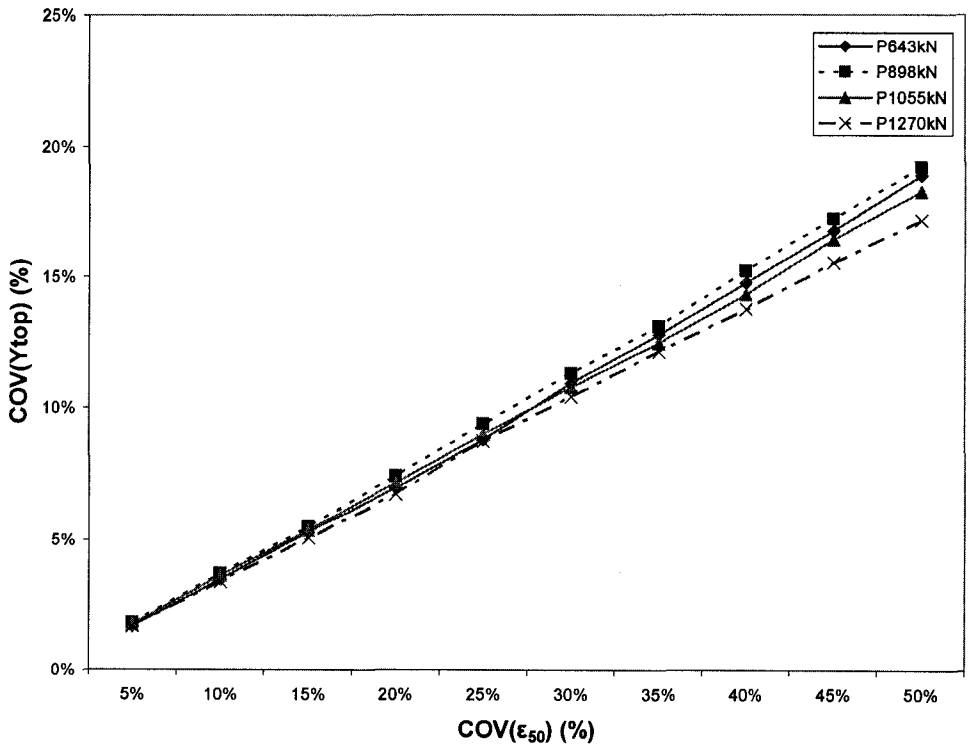

Fig. I.5 COV(Y_{Top}) for varying COV(ε_{50}) in hinged head long (10T) pile group with spacing (4D).

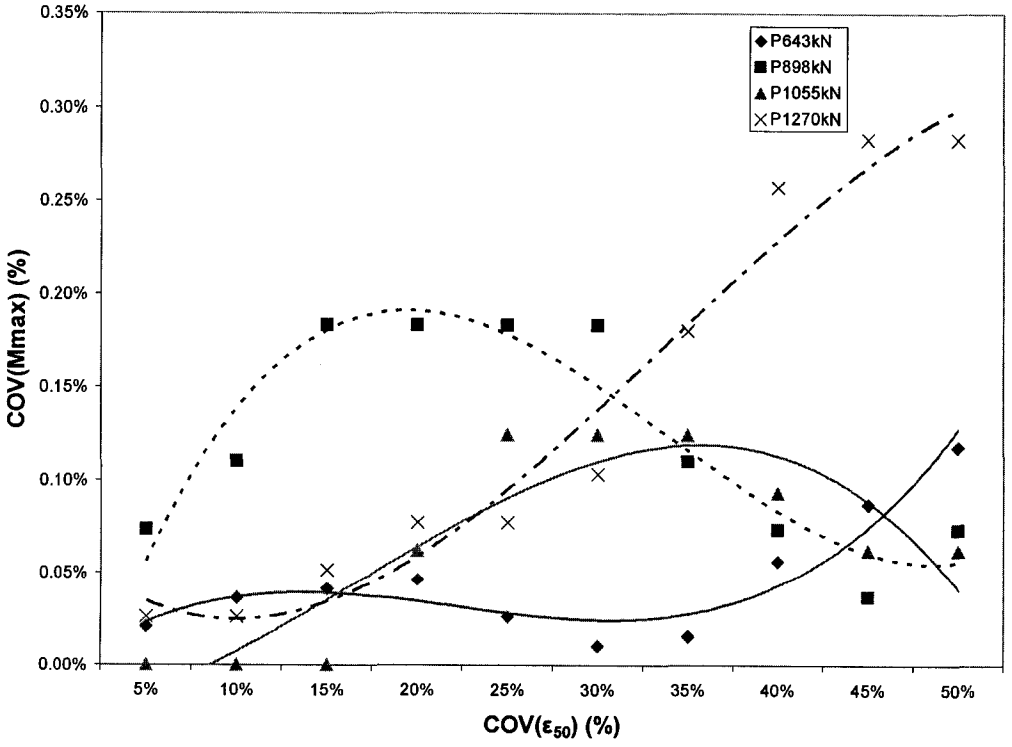

Fig. I.6(a) COV(M_{Max}) for varying COV(ε_{50}) for pile C in hinged head long pile group with spacing (4D).

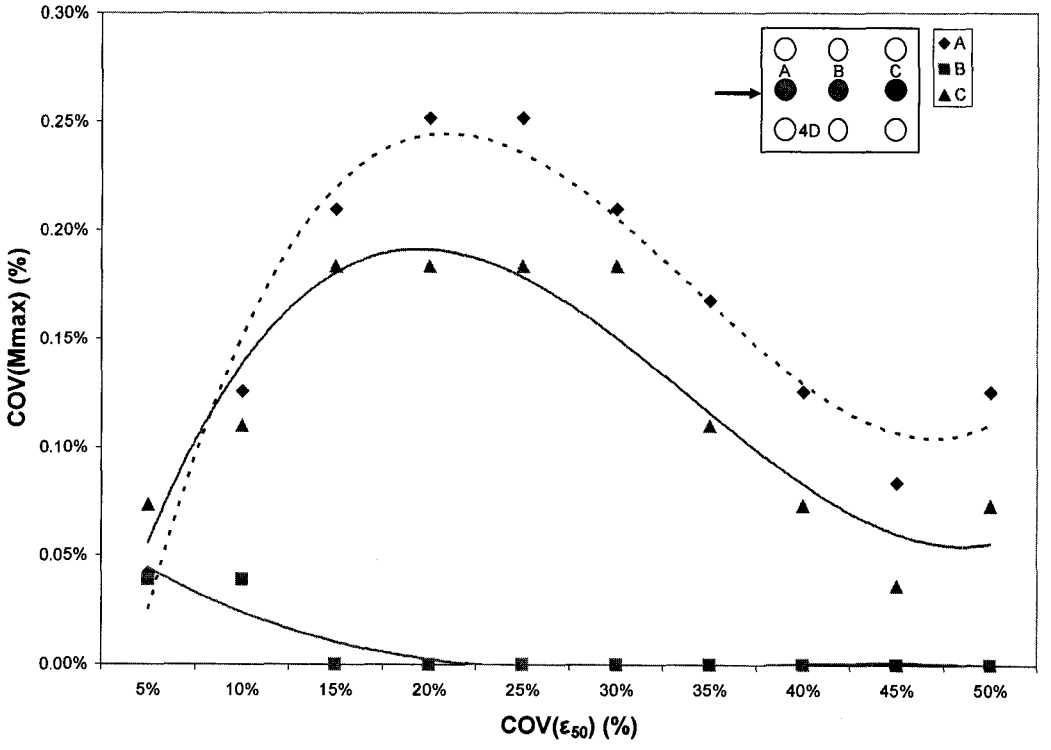

Fig. I.6(b) COV(M_{Max}) for varying COV(ε_{50}) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (4D) at the optimum lateral load 898 kN.

I.1.4 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (4D) and with 'EI' as varying random design variable

Table I.13. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 643 kN and 898 kN.

			P=643 kN (67, 72, 76 kN)				P=898 kN (93, 100, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00464	85.53	91.65	97.46	0.00733	119.2	127.9	136.4
45%	2.45E+09	60500	0.00438	85.52	91.64	97.47	0.00691	119.2	128	136.3
40%	1.94E+09	66000	0.00415	85.51	91.64	97.48	0.00653	119.2	128	136.3
35%	1.48E+09	71500	0.00395	85.51	91.64	97.49	0.00621	119.3	128.1	136.1
30%	1.09E+09	77000	0.00377	85.51	91.64	97.5	0.00591	119.5	128	136.1
25%	7.56E+08	82500	0.00361	85.51	91.63	97.5	0.00566	119.5	128	136.1
20%	4.84E+08	88000	0.00347	85.5	91.63	97.51	0.00544	119.4	128	136.1
15%	2.72E+08	93500	0.00334	85.51	91.63	97.5	0.00524	119.3	128.1	136.2
10%	1.21E+08	99000	0.00322	85.52	91.63	97.5	0.00506	119.2	128.1	136.2
5%	3.03E+07	104500	0.00312	85.52	91.63	97.5	0.00489	119.2	128.1	136.2
0%	0.00E+00	110000	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5%	3.03E+07	115500	0.00293	85.53	91.62	97.5	0.0046	119.1	128.1	136.4
10%	1.21E+08	121000	0.00285	85.53	91.62	97.5	0.00448	119	128	136.5
15%	2.72E+08	126500	0.00277	85.54	91.62	97.5	0.00435	119	128	136.5
20%	4.84E+08	132000	0.0027	85.53	91.63	97.5	0.00424	119	128	136.6
25%	7.56E+08	137500	0.00263	85.52	91.63	97.5	0.00414	118.9	128	136.6
30%	1.09E+09	143000	0.00257	85.52	91.64	97.51	0.00404	118.9	128	136.7
35%	1.48E+09	148500	0.00251	85.51	91.64	97.51	0.00396	118.9	128	136.7
40%	1.94E+09	154000	0.00246	85.51	91.64	97.51	0.00388	118.8	128	136.7
45%	2.45E+09	159500	0.0024	85.48	91.66	97.53	0.0038	118.8	128	136.7
50%	3.03E+09	165000	0.00235	85.45	91.67	97.54	0.00372	118.8	128	136.8

Table I.14. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1055 kN and 1270 kN.

			P=1055 kN (110, 120, 130 kN)				P=1270 kN (130, 140, 150 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00937	139.9	150.4	160.3	0.0127	167.7	181.1	193.6
45%	2.45E+09	60500	0.00879	139.8	150.4	160.3	0.0119	167.7	181.1	193.7
40%	1.94E+09	66000	0.00829	139.8	150.4	160.3	0.0112	167.6	181.1	193.7
35%	1.48E+09	71500	0.00786	139.7	150.5	160.4	0.0106	167.6	181.1	193.8
30%	1.09E+09	77000	0.00748	139.6	150.5	160.5	0.0101	167.5	181.1	193.8
25%	7.56E+08	82500	0.00715	139.6	150.4	160.6	0.00964	167.5	181.1	193.9
20%	4.84E+08	88000	0.00686	139.5	150.5	160.7	0.00922	167.5	181.1	193.9
15%	2.72E+08	93500	0.0066	139.4	150.5	160.7	0.00886	167.4	181.1	193.9
10%	1.21E+08	99000	0.00636	139.4	150.5	160.7	0.00853	167.4	181.1	194
5%	3.03E+07	104500	0.00614	139.4	150.5	160.8	0.00824	167.3	181.1	194
0%	0.00E+00	110000	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	3.03E+07	115500	0.00576	139.4	150.4	160.8	0.00772	167.3	181.1	194.1
10%	1.21E+08	121000	0.0056	139.4	150.4	160.8	0.00749	167.2	181.1	194.2
15%	2.72E+08	126500	0.00545	139.4	150.4	160.8	0.00728	167.2	181.1	194.2
20%	4.84E+08	132000	0.00531	139.4	150.4	160.8	0.00709	167.2	181.1	194.2
25%	7.56E+08	137500	0.00518	139.4	150.4	160.8	0.00691	167.2	181.1	194.3
30%	1.09E+09	143000	0.00506	139.4	150.4	160.8	0.00675	167.1	181.1	194.3
35%	1.48E+09	148500	0.00495	139.4	150.4	160.8	0.0066	167	181.1	194.3
40%	1.94E+09	154000	0.00485	139.4	150.4	160.8	0.00645	167	181.1	194.3
45%	2.45E+09	159500	0.00475	139.4	150.4	160.8	0.00631	167	181.1	194.4
50%	3.03E+09	165000	0.00466	139.4	150.4	160.8	0.00618	167	181.1	194.4

Table I.15(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 643 kN and 898 kN.

		P=643 kN		P=898 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	9.03E-09	3.146%	2.10E-08	3.059%
10%	1.21E+08	3.42E-08	6.126%	8.41E-08	6.118%
15%	2.72E+08	8.12E-08	9.437%	1.98E-07	9.388%
20%	4.84E+08	1.48E-07	12.748%	3.60E-07	12.658%
25%	7.56E+08	2.40E-07	16.225%	5.78E-07	16.034%
30%	1.09E+09	3.60E-07	19.868%	8.74E-07	19.726%
35%	1.48E+09	5.18E-07	23.841%	1.27E-06	23.734%
40%	1.94E+09	7.14E-07	27.980%	1.76E-06	27.954%
45%	2.45E+09	9.80E-07	32.781%	2.42E-06	32.806%
50%	3.03E+09	1.31E-06	37.914%	3.26E-06	38.080%

Table I.15(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1055 kN and 1270 kN.

		P=1055 kN		P=1270 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	3.61E-08	3.193%	6.76E-08	3.262%
10%	1.21E+08	1.44E-07	6.387%	2.70E-07	6.524%
15%	2.72E+08	3.31E-07	9.664%	6.24E-07	9.912%
20%	4.84E+08	6.01E-07	13.025%	1.13E-06	13.363%
25%	7.56E+08	9.70E-07	16.555%	1.86E-06	17.127%
30%	1.09E+09	1.46E-06	20.336%	2.81E-06	21.016%
35%	1.48E+09	2.12E-06	24.454%	4.00E-06	25.094%
40%	1.94E+09	2.96E-06	28.908%	5.64E-06	29.799%
45%	2.45E+09	4.08E-06	33.950%	7.81E-06	35.069%
50%	3.03E+09	5.55E-06	39.580%	1.06E-05	40.903%

Table I.16(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 643 kN.

		P=643 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	2.5E-05	2.5E-05	0	0.01%	0.01%	0.00%
10%	1.21E+08	2.5E-05	2.5E-05	0	0.01%	0.01%	0.00%
15%	2.72E+08	0.000225	2.5E-05	0	0.02%	0.01%	0.00%
20%	4.84E+08	0.000225	0	2.5E-05	0.02%	0.00%	0.01%
25%	7.56E+08	2.5E-05	0	0	0.01%	0.00%	0.00%
30%	1.09E+09	2.5E-05	0	2.5E-05	0.01%	0.00%	0.01%
35%	1.48E+09	0	0	0.0001	0.00%	0.00%	0.01%
40%	1.94E+09	0	0	0.000225	0.00%	0.00%	0.02%
45%	2.45E+09	0.0004	1E-04	0.0009	0.02%	0.01%	0.03%
50%	3.03E+09	0.0016	1E-04	0.0016	0.05%	0.01%	0.04%

Table I.16(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 898 kN.

		P=898 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.0025	0	0.01	0.04%	0.00%	0.07%
10%	1.21E+08	0.01	0.0025	0.0225	0.08%	0.04%	0.11%
15%	2.72E+08	0.0225	0.0025	0.0225	0.13%	0.04%	0.11%
20%	4.84E+08	0.04	0	0.0625	0.17%	0.00%	0.18%
25%	7.56E+08	0.09	0	0.0625	0.25%	0.00%	0.18%
30%	1.09E+09	0.09	0	0.09	0.25%	0.00%	0.22%
35%	1.48E+09	0.04	0.0025	0.09	0.17%	0.04%	0.22%
40%	1.94E+09	0.04	0	0.04	0.17%	0.00%	0.15%
45%	2.45E+09	0.04	0	0.04	0.17%	0.00%	0.15%
50%	3.03E+09	0.04	0.0025	0.04	0.17%	0.04%	0.15%

Table I.16(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1055 kN.

		P=1055 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0	0.0025	0	0.00%	0.03%	0.00%
10%	1.21E+08	0	0.0025	0.0025	0.00%	0.03%	0.03%
15%	2.72E+08	0	0.0025	0.0025	0.00%	0.03%	0.03%
20%	4.84E+08	0.0025	0.0025	0.0025	0.04%	0.03%	0.03%
25%	7.56E+08	0.01	0	0.01	0.07%	0.00%	0.06%
30%	1.09E+09	0.01	0.0025	0.0225	0.07%	0.03%	0.09%
35%	1.48E+09	0.0225	0.0025	0.04	0.11%	0.03%	0.12%
40%	1.94E+09	0.04	0	0.0625	0.14%	0.00%	0.16%
45%	2.45E+09	0.04	0	0.0625	0.14%	0.00%	0.16%
50%	3.03E+09	0.0625	0	0.0625	0.18%	0.00%	0.16%

Table I.16(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1270 kN.

		P=1270 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0	0.00E+00	0.0025	0.00%	0.00%	0.03%
10%	1.21E+08	0.01	0.00E+00	0.01	0.06%	0.00%	0.05%
15%	2.72E+08	0.01	0.00E+00	0.0225	0.06%	0.00%	0.08%
20%	4.84E+08	0.0225	0.00E+00	0.0225	0.09%	0.00%	0.08%
25%	7.56E+08	0.0225	0.00E+00	0.04	0.09%	0.00%	0.10%
30%	1.09E+09	0.04	0.00E+00	0.0625	0.12%	0.00%	0.13%
35%	1.48E+09	0.09	0.00E+00	0.0625	0.18%	0.00%	0.13%
40%	1.94E+09	0.09	0.00E+00	0.09	0.18%	0.00%	0.15%
45%	2.45E+09	0.1225	0.00E+00	0.1225	0.21%	0.00%	0.18%
50%	3.03E+09	0.1225	0.00E+00	0.16	0.21%	0.00%	0.21%

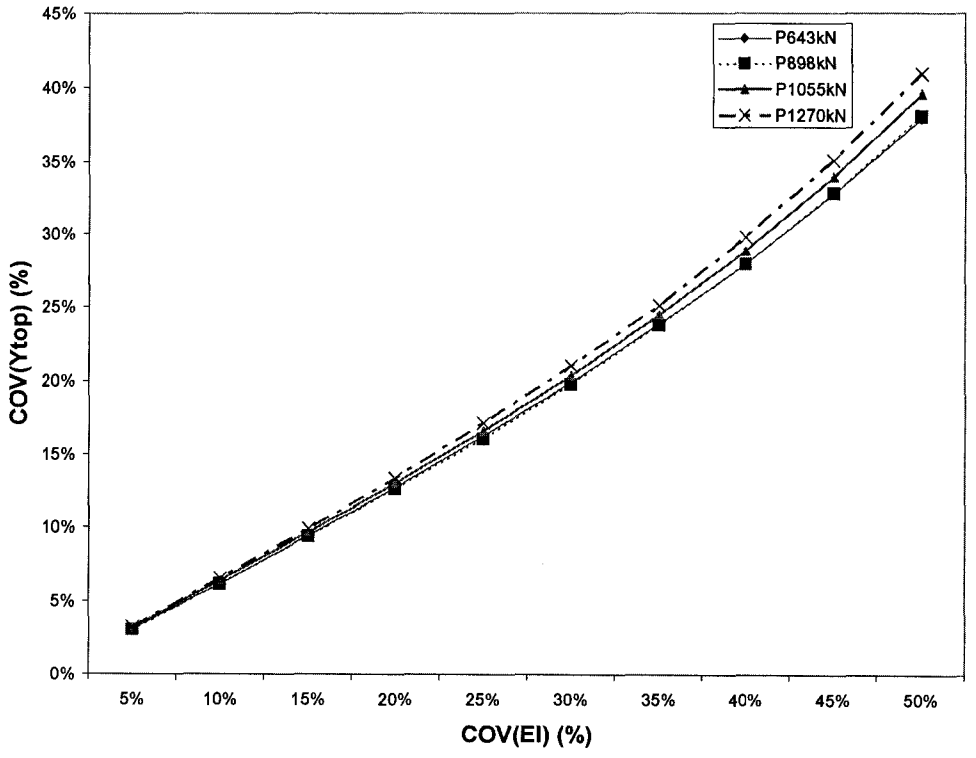

Fig. I.7 COV(Y_{Top}) for varying COV(EI) in hinged head long (10T) pile group with spacing (4D).

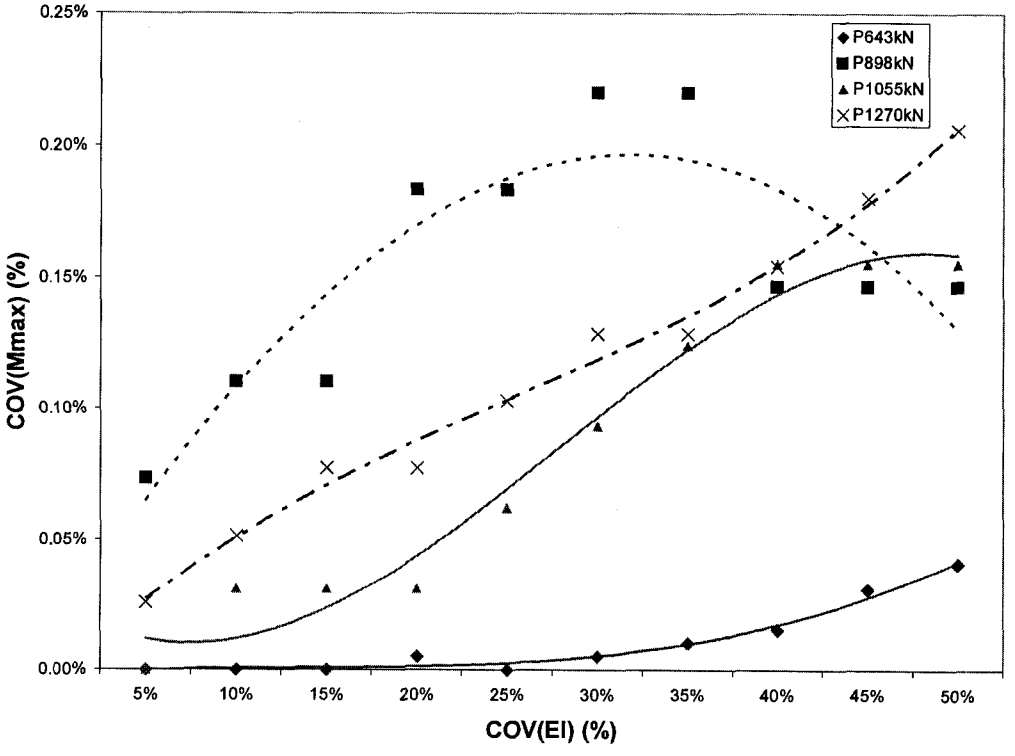

Fig. I.8(a) COV(M_{Max}) for varying COV(EI) for pile C in hinged head long pile group with spacing (4D).

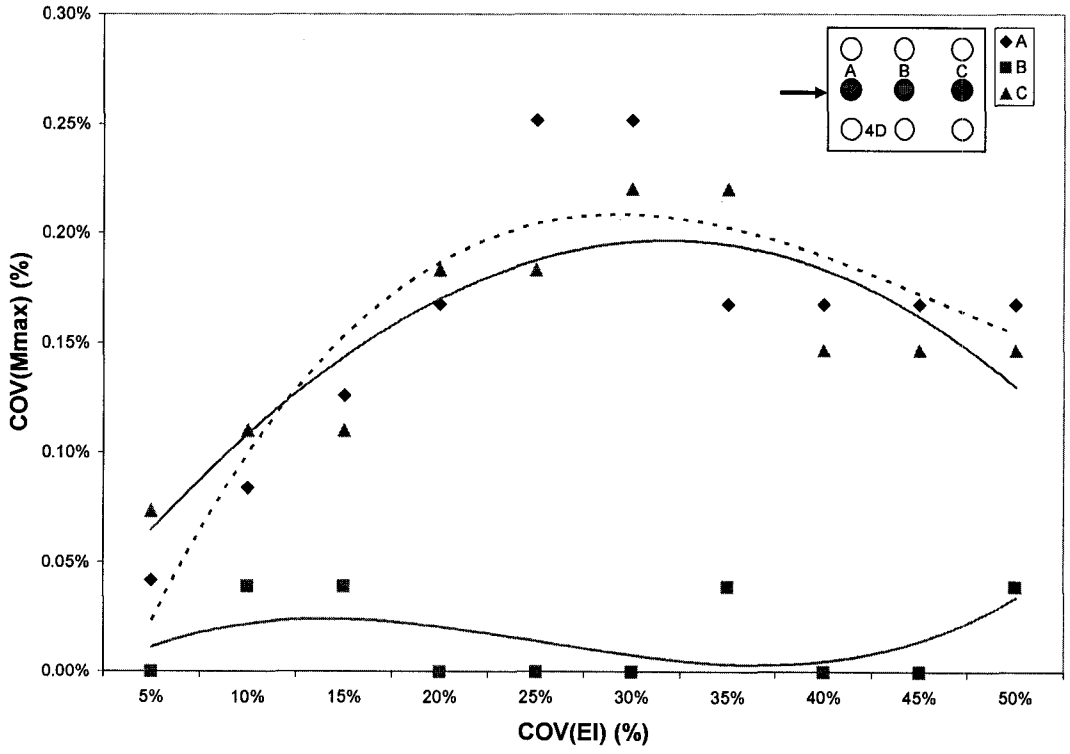

Fig. I.8(b) COV(M_{Max}) for varying COV(EI) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (4D) at the optimum lateral load 898 kN.

I.1.5 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (4D) and with 'k' as varying random design variable

Table I.17. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 643 kN and 898 kN.

			P=643 kN (67, 72, 76 kN)				P=898 kN (93, 100, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00313	86.14	91.65	96.87	0.00484	119.1	128	136.5
45%	3.75E+09	74800	0.00306	85.26	91.65	97.74	0.00482	119.2	128	136.4
40%	2.96E+09	81600	0.00305	85.3	91.64	97.71	0.0048	119.3	128	136.3
35%	2.27E+09	88400	0.00305	85.34	91.64	97.67	0.00478	119.3	128	136.3
30%	1.66E+09	95200	0.00304	85.37	91.64	97.64	0.00477	119.4	128	136.2
25%	1.16E+09	102000	0.00303	85.4	91.64	97.61	0.00476	119.4	128	136.3
20%	7.40E+08	108800	0.00303	85.42	91.63	97.6	0.00475	119.3	128	136.3
15%	4.16E+08	115600	0.00303	85.45	91.63	97.57	0.00475	119.2	128.1	136.3
10%	1.85E+08	122400	0.00303	85.47	91.63	97.55	0.00475	119.2	128.1	136.3
5%	4.62E+07	129200	0.00302	85.5	91.63	97.52	0.00474	119.2	128.1	136.3
0%	0.00E+00	136000	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5%	4.62E+07	142800	0.00302	85.55	91.62	97.48	0.00474	119.1	128.1	136.4
10%	1.85E+08	149600	0.00302	85.56	91.63	97.46	0.00473	119.1	128	136.4
15%	4.16E+08	156400	0.00302	85.56	91.64	97.45	0.00473	119.1	128	136.4
20%	7.40E+08	163200	0.00302	85.56	91.64	97.44	0.00473	119.1	128	136.4
25%	1.16E+09	170000	0.00301	85.55	91.66	97.44	0.00473	119.1	128	136.4
30%	1.66E+09	176800	0.003	85.6	91.63	97.43	0.00473	119.1	128	136.4
35%	2.27E+09	183600	0.003	85.59	91.64	97.43	0.00473	119.1	128	136.4
40%	2.96E+09	190400	0.003	85.57	91.65	97.43	0.00473	119.1	128	136.4
45%	3.75E+09	197200	0.003	85.56	91.66	97.43	0.00473	119.1	128	136.4
50%	4.62E+09	204000	0.003	85.54	91.68	97.43	0.00473	119.1	128	136.4

Table I.18. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1055 kN and 1270 kN.

			P=1055 kN (110, 120, 130 kN)				P=1270 kN (130, 140, 150 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00604	139.6	150.4	160.6	0.00799	167.5	181.3	193.5
45%	3.75E+09	74800	0.00601	139.8	150.4	160.5	0.00797	167.3	181.1	194
40%	2.96E+09	81600	0.00598	139.9	150.4	160.4	0.00797	167.3	181.1	194.1
35%	2.27E+09	88400	0.00596	139.7	150.5	160.4	0.00797	167.3	181.1	194.1
30%	1.66E+09	95200	0.00596	139.5	150.5	160.5	0.00797	167.3	181.1	194.1
25%	1.16E+09	102000	0.00595	139.4	150.5	160.6	0.00797	167.3	181.1	194.1
20%	7.40E+08	108800	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
15%	4.16E+08	115600	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
10%	1.85E+08	122400	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	4.62E+07	129200	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
0%	0.00E+00	136000	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	4.62E+07	142800	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
10%	1.85E+08	149600	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
15%	4.16E+08	156400	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
20%	7.40E+08	163200	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
25%	1.16E+09	170000	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
30%	1.66E+09	176800	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
35%	2.27E+09	183600	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
40%	2.96E+09	190400	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
45%	3.75E+09	197200	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
50%	4.62E+09	204000	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1

Table I.19(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 643 kN and 898 kN.

		P=643 kN		P=898 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	2.50E-11	0.166%	1.00E-10	0.211%
15%	4.16E+08	2.50E-11	0.166%	1.00E-10	0.211%
20%	7.40E+08	2.50E-11	0.166%	1.00E-10	0.211%
25%	1.16E+09	1.00E-10	0.331%	2.25E-10	0.316%
30%	1.66E+09	4.00E-10	0.662%	4.00E-10	0.422%
35%	2.27E+09	6.25E-10	0.828%	6.25E-10	0.527%
40%	2.96E+09	6.25E-10	0.828%	1.22E-09	0.738%
45%	3.75E+09	9.00E-10	0.993%	2.02E-09	0.949%
50%	4.62E+09	4.22E-09	2.152%	3.02E-09	1.160%

Table I.19(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1055 kN and 1270 kN.

		P=1055 kN		P=1270 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	0.00E+00	0.000%
20%	7.40E+08	0.00E+00	0.000%	0.00E+00	0.000%
25%	1.16E+09	0.00E+00	0.000%	0.00E+00	0.000%
30%	1.66E+09	2.50E-11	0.084%	0.00E+00	0.000%
35%	2.27E+09	2.50E-11	0.084%	0.00E+00	0.000%
40%	2.96E+09	2.25E-10	0.252%	0.00E+00	0.000%
45%	3.75E+09	9.00E-10	0.504%	0.00E+00	0.000%
50%	4.62E+09	2.02E-09	0.756%	1.00E-10	0.125%

Table I.20(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 643 kN.

		P=643 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.000625	2.5E-05	0.0004	0.03%	0.01%	0.02%
10%	1.85E+08	0.002025	0	0.002025	0.05%	0.00%	0.05%
15%	4.16E+08	0.003025	2.5E-05	0.0036	0.06%	0.01%	0.06%
20%	7.40E+08	0.0049	2.5E-05	0.0064	0.08%	0.01%	0.08%
25%	1.16E+09	0.005625	1E-04	0.00289	0.09%	0.01%	0.06%
30%	1.66E+09	0.013225	2.5E-05	0.011025	0.13%	0.01%	0.11%
35%	2.27E+09	0.015625	0	0.0144	0.15%	0.00%	0.12%
40%	2.96E+09	0.018225	2.5E-05	0.0196	0.16%	0.01%	0.14%
45%	3.75E+09	0.0225	2.5E-05	0.024025	0.18%	0.01%	0.16%
50%	4.62E+09	0.09	0.000225	0.0784	0.35%	0.02%	0.29%

Table I.20(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 898 kN.

		P=898 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.0025	0	0.0025	0.04%	0.00%	0.04%
10%	1.85E+08	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
15%	4.16E+08	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
20%	7.40E+08	0.01	0	0.0025	0.08%	0.00%	0.04%
25%	1.16E+09	0.0225	0	0.0025	0.13%	0.00%	0.04%
30%	1.66E+09	0.0225	0	0.01	0.13%	0.00%	0.07%
35%	2.27E+09	0.01	0	0.0025	0.08%	0.00%	0.04%
40%	2.96E+09	0.01	0	0.0025	0.08%	0.00%	0.04%
45%	3.75E+09	0.0025	0	0	0.04%	0.00%	0.00%
50%	4.62E+09	0	0	0.0025	0.00%	0.00%	0.04%

Table I.20(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1055 kN.

		P=1055 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0	0	0.00%	0.00%	0.00%
10%	1.85E+08	0	0	0	0.00%	0.00%	0.00%
15%	4.16E+08	0	0	0	0.00%	0.00%	0.00%
20%	7.40E+08	0	0	0	0.00%	0.00%	0.00%
25%	1.16E+09	0	0	0.01	0.00%	0.00%	0.06%
30%	1.66E+09	0.0025	0	0.0225	0.04%	0.00%	0.09%
35%	2.27E+09	0.0225	0	0.04	0.11%	0.00%	0.12%
40%	2.96E+09	0.0625	0.0025	0.04	0.18%	0.03%	0.12%
45%	3.75E+09	0.04	0.0025	0.0225	0.14%	0.03%	0.09%
50%	4.62E+09	0.01	0.0025	0.01	0.07%	0.03%	0.06%

Table I.20(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1270 kN.

		P=1270 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0	0	0.00%	0.00%	0.00%
10%	1.85E+08	0	0	0	0.00%	0.00%	0.00%
15%	4.16E+08	0	0	0	0.00%	0.00%	0.00%
20%	7.40E+08	0	0	0	0.00%	0.00%	0.00%
25%	1.16E+09	0	0	0	0.00%	0.00%	0.00%
30%	1.66E+09	0	0	0	0.00%	0.00%	0.00%
35%	2.27E+09	0	0	0	0.00%	0.00%	0.00%
40%	2.96E+09	0	0	0	0.00%	0.00%	0.00%
45%	3.75E+09	0	0	0.0025	0.00%	0.00%	0.03%
50%	4.62E+09	0.01	0.01	0.09	0.06%	0.06%	0.15%

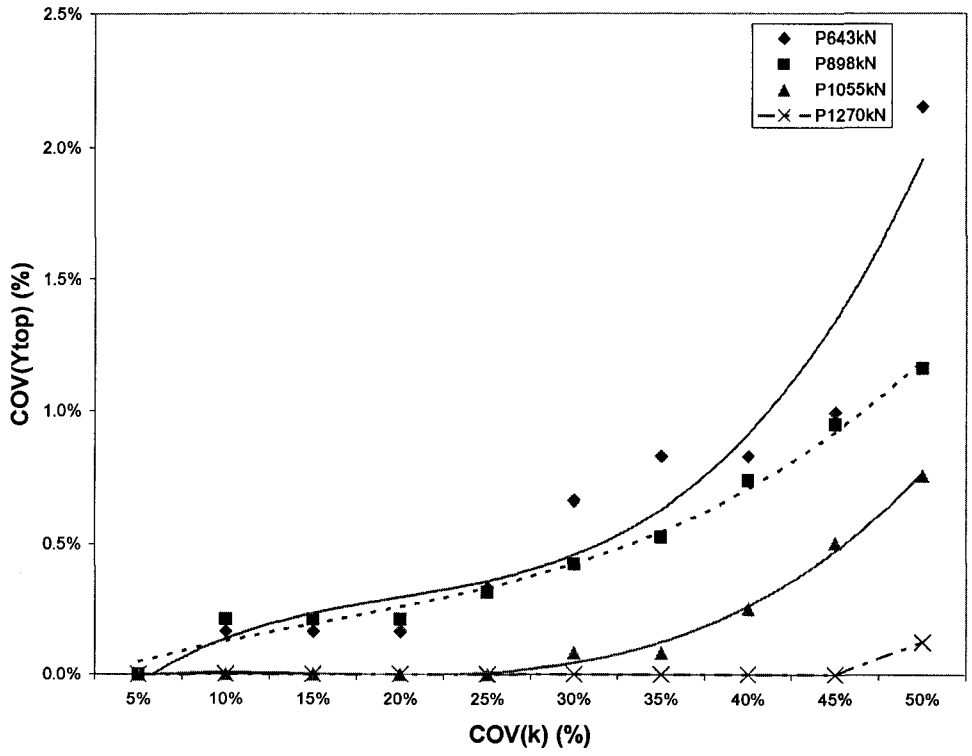

Fig. I.9 COV(Y_{Top}) for varying COV(k) in hinged head long (10T) pile group with spacing (4D).

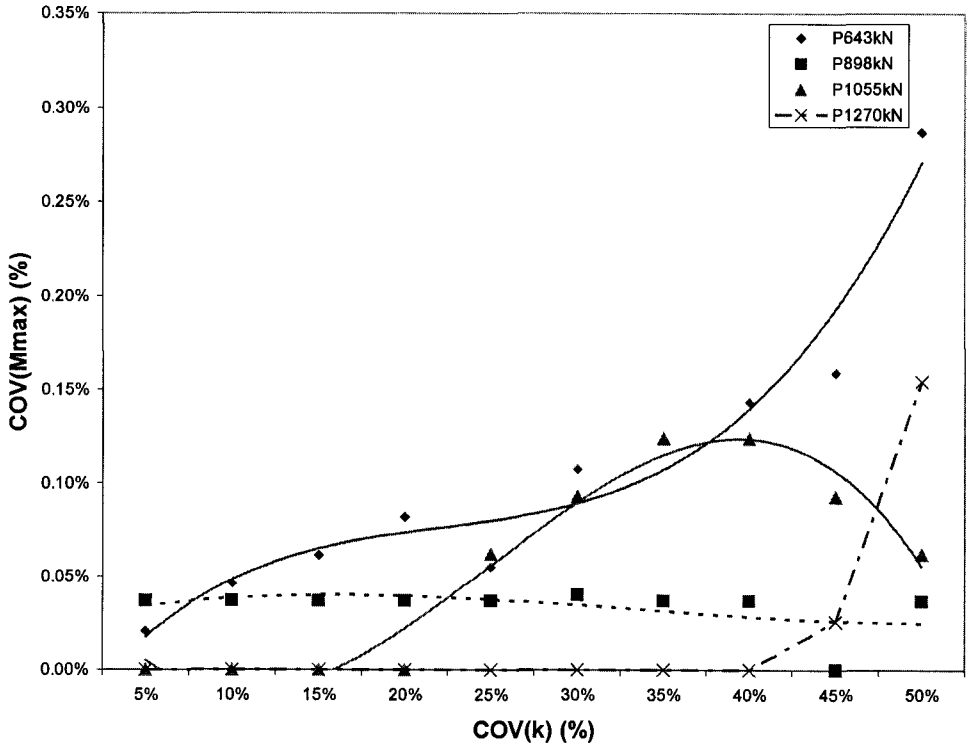

Fig. I.10(a) COV(M_{Max}) for varying COV(k) for pile C in hinged head long pile group with spacing (4D).

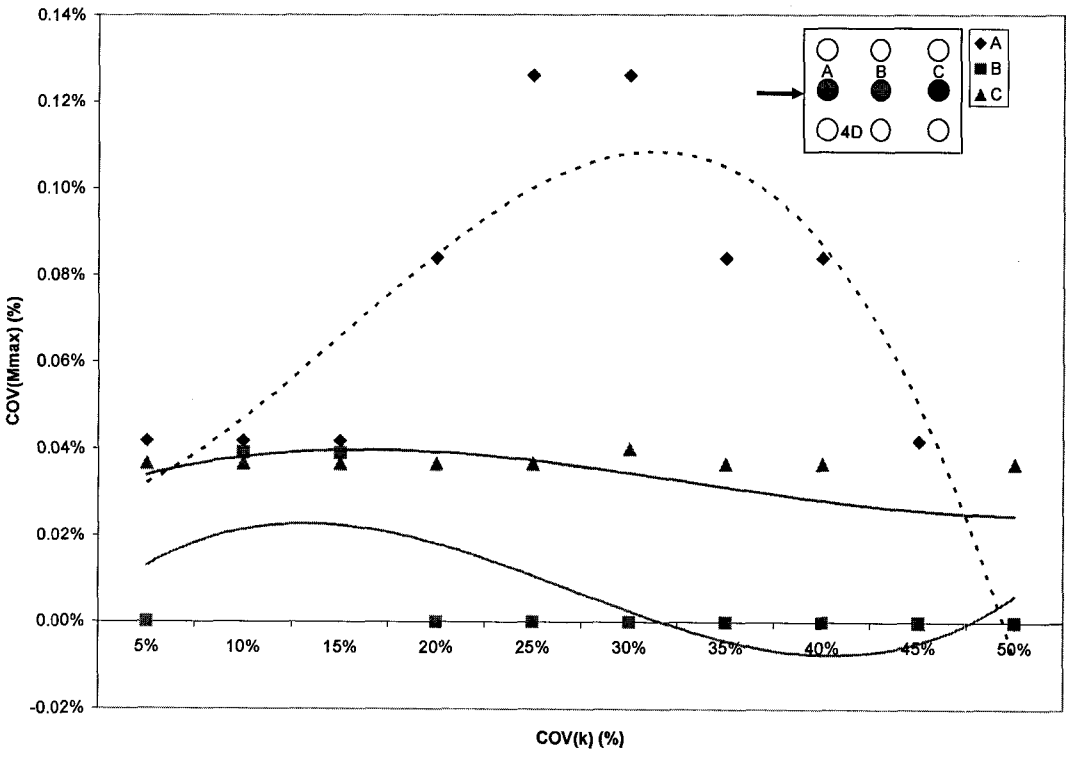

Fig. I.10(b) COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (4D) at the optimum lateral load 898 kN.

I.1.6 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (4D) and with 'γ'' as varying random design variable

Table I.21. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 643 kN and 898 kN.

			P=643 kN (67, 72, 76 kN)				P=898 kN (93, 100, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00303	85.53	91.62	97.49	0.00475	119.1	128.1	136.3
45%	7.049025	3.245	0.00303	85.53	91.62	97.5	0.00475	119.1	128.1	136.3
40%	5.5696	3.54	0.00303	85.53	91.62	97.5	0.00475	119.2	128.1	136.3
35%	4.264225	3.835	0.00303	85.53	91.62	97.5	0.00475	119.2	128.1	136.3
30%	3.1329	4.13	0.00303	85.53	91.62	97.5	0.00475	119.2	128.1	136.3
25%	2.175625	4.425	0.00303	85.53	91.62	97.5	0.00475	119.2	128.1	136.3
20%	1.3924	4.72	0.00303	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
15%	0.783225	5.015	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
10%	0.3481	5.31	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5%	0.087025	5.605	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
0%	0	5.9	0.00302	85.53	91.62	97.5	0.00474	119.2	128.1	136.3
5%	0.087025	6.195	0.00302	85.53	91.62	97.5	0.00473	119.2	128.1	136.3
10%	0.3481	6.49	0.00302	85.53	91.62	97.5	0.00473	119.2	128.1	136.3
15%	0.783225	6.785	0.00302	85.53	91.62	97.5	0.00473	119.2	128.1	136.3
20%	1.3924	7.08	0.00302	85.53	91.62	97.5	0.00473	119.2	128.1	136.3
25%	2.175625	7.375	0.00302	85.52	91.62	97.5	0.00473	119.2	128.1	136.3
30%	3.1329	7.67	0.00301	85.52	91.62	97.5	0.00473	119.2	128.1	136.3
35%	4.264225	7.965	0.00301	85.52	91.62	97.5	0.00472	119.2	128.1	136.3
40%	5.5696	8.26	0.00301	85.52	91.62	97.5	0.00472	119.2	128.1	136.3
45%	7.049025	8.555	0.00301	85.52	91.62	97.5	0.00472	119.2	128.1	136.3
50%	8.7025	8.85	0.00301	85.52	91.62	97.5	0.00472	119.2	128.1	136.3

Table I.22. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 1055 kN and 1270 kN.

			P=1055 kN (110, 120, 130 kN)				P=1270 kN (130, 140, 150 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00597	139.3	150.5	160.8	0.008	167.3	181.1	194.1
45%	7.049025	3.245	0.00597	139.3	150.5	160.8	0.008	167.3	181.1	194.1
40%	5.5696	3.54	0.00597	139.3	150.5	160.8	0.008	167.3	181.1	194.1
35%	4.264225	3.835	0.00597	139.4	150.5	160.8	0.00799	167.3	181.1	194.1
30%	3.1329	4.13	0.00596	139.4	150.5	160.8	0.00799	167.3	181.1	194.1
25%	2.175625	4.425	0.00596	139.4	150.5	160.8	0.00799	167.3	181.1	194.1
20%	1.3924	4.72	0.00596	139.4	150.5	160.8	0.00798	167.3	181.1	194.1
15%	0.783225	5.015	0.00596	139.4	150.5	160.8	0.00798	167.3	181.1	194.1
10%	0.3481	5.31	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	0.087025	5.605	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
0%	0	5.9	0.00595	139.4	150.5	160.8	0.00797	167.3	181.1	194.1
5%	0.087025	6.195	0.00595	139.4	150.5	160.8	0.00796	167.3	181.1	194.1
10%	0.3481	6.49	0.00594	139.4	150.5	160.8	0.00796	167.3	181.1	194.1
15%	0.783225	6.785	0.00594	139.4	150.5	160.8	0.00796	167.3	181.1	194.1
20%	1.3924	7.08	0.00594	139.4	150.5	160.8	0.00795	167.3	181.1	194.1
25%	2.175625	7.375	0.00594	139.4	150.5	160.8	0.00795	167.3	181.1	194.1
30%	3.1329	7.67	0.00593	139.4	150.5	160.8	0.00794	167.3	181.1	194.1
35%	4.264225	7.965	0.00593	139.4	150.5	160.8	0.00794	167.3	181.1	194.1
40%	5.5696	8.26	0.00593	139.4	150.5	160.8	0.00794	167.3	181.1	194
45%	7.049025	8.555	0.00593	139.4	150.5	160.8	0.00793	167.3	181.1	194
50%	8.7025	8.85	0.00592	139.4	150.5	160.8	0.00793	167.3	181.1	194

Table I.23(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 643 kN and 898 kN.

		P=643 kN		P=898 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	2.50E-11	0.105%
10%	3.48E-01	0.00E+00	0.000%	2.50E-11	0.105%
15%	7.83E-01	0.00E+00	0.000%	2.50E-11	0.105%
20%	1.39E+00	2.50E-11	0.166%	2.50E-11	0.105%
25%	2.18E+00	2.50E-11	0.166%	1.00E-10	0.211%
30%	3.13E+00	1.00E-10	0.331%	1.00E-10	0.211%
35%	4.26E+00	1.00E-10	0.331%	2.25E-10	0.316%
40%	5.57E+00	1.00E-10	0.331%	2.25E-10	0.316%
45%	7.05E+00	1.00E-10	0.331%	2.25E-10	0.316%
50%	8.70E+00	1.00E-10	0.331%	2.25E-10	0.316%

Table I.23(b) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 1055 kN and 1270 kN.

		P=1055 kN		P=1270 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	8.70E-02	0.00E+00	0.000%	2.50E-11	0.063%
10%	3.48E-01	2.50E-11	0.084%	2.50E-11	0.063%
15%	7.83E-01	1.00E-10	0.168%	1.00E-10	0.125%
20%	1.39E+00	1.00E-10	0.168%	2.25E-10	0.188%
25%	2.18E+00	1.00E-10	0.168%	4.00E-10	0.251%
30%	3.13E+00	2.25E-10	0.252%	6.25E-10	0.314%
35%	4.26E+00	4.00E-10	0.336%	6.25E-10	0.314%
40%	5.57E+00	4.00E-10	0.336%	9.00E-10	0.376%
45%	7.05E+00	4.00E-10	0.336%	1.23E-09	0.439%
50%	8.70E+00	6.25E-10	0.420%	1.23E-09	0.439%

Table I.24(a) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 643 kN.

		P=643 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.3924	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.175625	2.50E-05	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
30%	3.1329	2.50E-05	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
35%	4.264225	2.50E-05	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
40%	5.5696	2.50E-05	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
45%	7.049025	2.50E-05	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
50%	8.7025	2.50E-05	0.00E+00	2.50E-05	0.01%	0.00%	0.01%

Table I.24(b) Value of $COV(M_{Max})$ for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 898 kN.

		P=898 kN					
		$VAR(M_{Max})$ $(kN\text{-}m)^2$			$COV(M_{Max})$ (%)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.3924	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.175625	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.1329	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.264225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.5696	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	7.049025	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
50%	8.7025	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%

Table I.24(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'γ' and lateral load 1055 kN.

		P=1055 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.3924	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.175625	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.1329	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.264225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.5696	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
45%	7.049025	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
50%	8.7025	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%

Table I.24(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (4D) and with varying 'γ' and lateral load 1270 kN.

		P=1270 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.3924	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.175625	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.1329	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.264225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.5696	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
45%	7.049025	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
50%	8.7025	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%

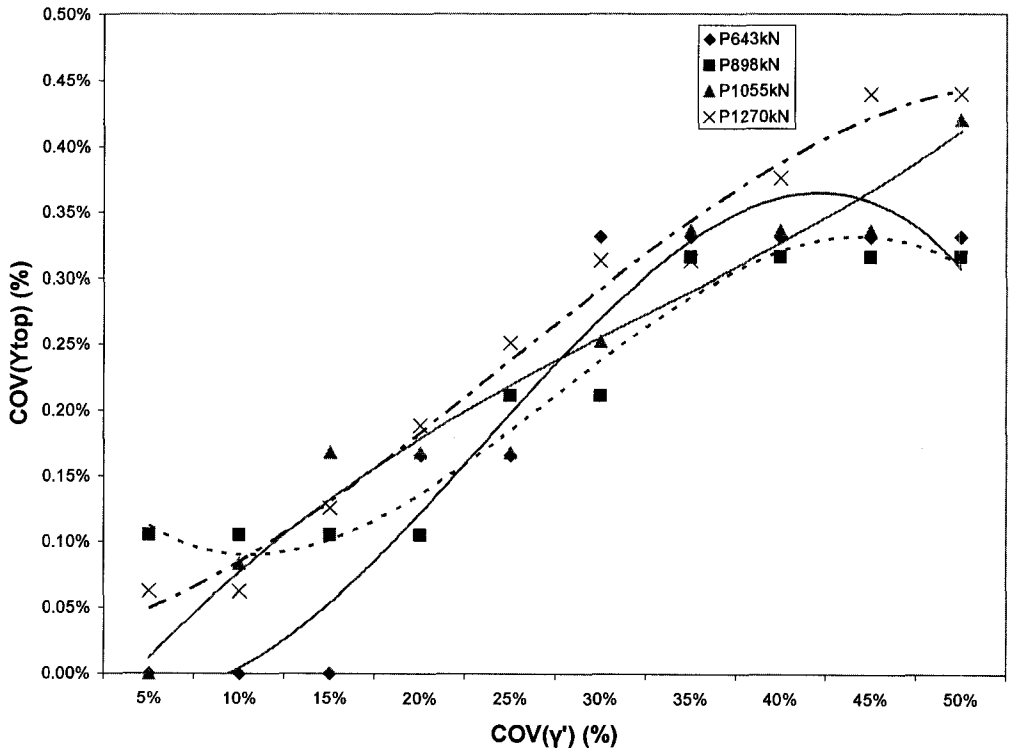

Fig. I.11 COV(Y_{Top}) for varying COV(γ') in hinged head long (10T) pile group with spacing (4D).

Note: Value of COV(M_{MAX}) is zero for pile rows A, B, C with varying COV(γ') in hinged head long (10T) pile group with spacing (4D).

I.2 Reliability analysis of hinged head long pile (10T) group with spacing (4D)

I.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 643 kN

$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00998$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06\ m^2$

Table I.25 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 643 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	4.00E-10	6.76E-06	3.84	1.10E-08	6.77E-06	3.84
10%	6.76E-06	2.02E-09	6.76E-06	3.84	4.41E-08	6.80E-06	3.83
15%	6.76E-06	4.90E-09	6.76E-06	3.84	1.02E-07	6.86E-06	3.81
20%	6.76E-06	7.23E-09	6.77E-06	3.84	1.98E-07	6.96E-06	3.78
25%	6.76E-06	3.60E-09	6.76E-06	3.84	3.25E-07	7.08E-06	3.75
30%	6.76E-06	6.25E-10	6.76E-06	3.84	4.97E-07	7.26E-06	3.70
35%	6.76E-06	2.50E-11	6.76E-06	3.84	7.48E-07	7.51E-06	3.64
40%	6.76E-06	3.02E-09	6.76E-06	3.84	1.06E-06	7.82E-06	3.57
45%	6.76E-06	1.10E-08	6.77E-06	3.84	1.51E-06	8.27E-06	3.47
50%	6.76E-06	3.42E-08	6.79E-06	3.83	2.12E-06	8.88E-06	3.35

Table I.26 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 643 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-09	6.76E-06	3.84	9.03E-09	6.77E-06	3.84
10%	6.76E-06	1.10E-08	6.77E-06	3.84	3.42E-08	6.79E-06	3.83
15%	6.76E-06	2.56E-08	6.79E-06	3.83	8.12E-08	6.84E-06	3.82
20%	6.76E-06	4.41E-08	6.80E-06	3.83	1.48E-07	6.91E-06	3.80
25%	6.76E-06	7.02E-08	6.83E-06	3.82	2.40E-07	7.00E-06	3.77
30%	6.76E-06	1.09E-07	6.87E-06	3.81	3.60E-07	7.12E-06	3.74
35%	6.76E-06	1.48E-07	6.91E-06	3.80	5.18E-07	7.28E-06	3.70
40%	6.76E-06	1.98E-07	6.96E-06	3.78	7.14E-07	7.47E-06	3.65
45%	6.76E-06	2.55E-07	7.02E-06	3.77	9.80E-07	7.74E-06	3.59
50%	6.76E-06	3.25E-07	7.08E-06	3.75	1.31E-06	8.07E-06	3.51

Table I.27 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 643 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.84	0.00E+00	6.76E-06	3.84
10%	6.76E-06	0.00E+00	6.76E-06	3.84	2.50E-11	6.76E-06	3.84
15%	6.76E-06	0.00E+00	6.76E-06	3.84	2.50E-11	6.76E-06	3.84
20%	6.76E-06	2.50E-11	6.76E-06	3.84	2.50E-11	6.76E-06	3.84
25%	6.76E-06	2.50E-11	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
30%	6.76E-06	1.00E-10	6.76E-06	3.84	4.00E-10	6.76E-06	3.84
35%	6.76E-06	1.00E-10	6.76E-06	3.84	6.25E-10	6.76E-06	3.84
40%	6.76E-06	1.00E-10	6.76E-06	3.84	6.25E-10	6.76E-06	3.84
45%	6.76E-06	1.00E-10	6.76E-06	3.84	9.00E-10	6.76E-06	3.84
50%	6.76E-06	1.00E-10	6.76E-06	3.84	4.22E-09	6.76E-06	3.84

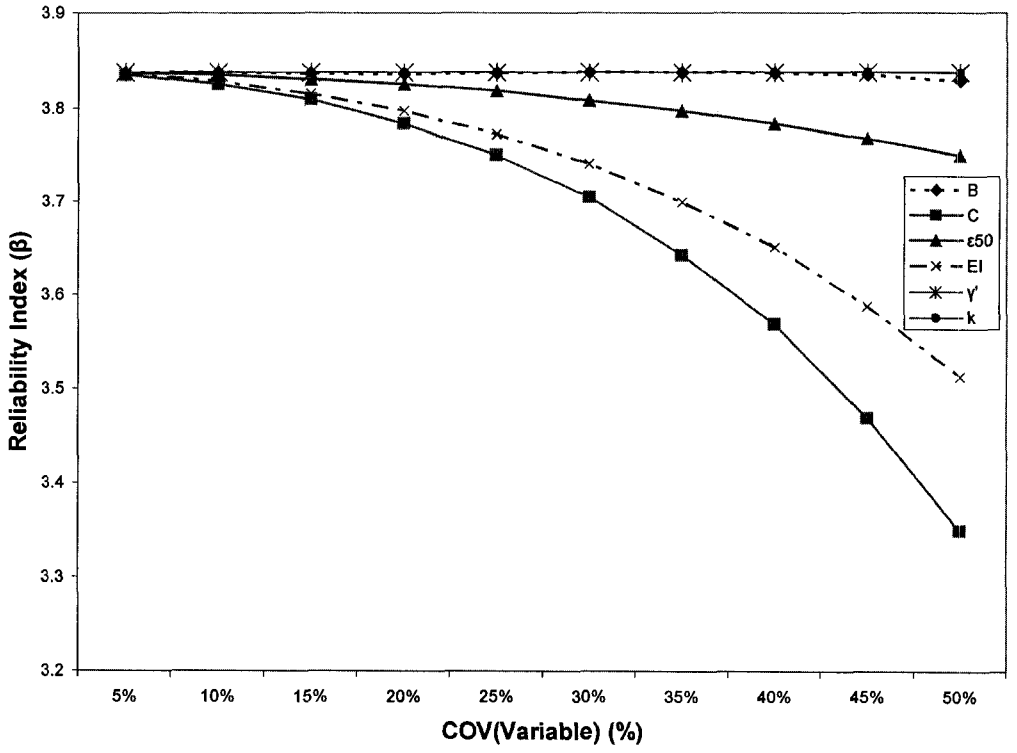

Fig. I.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (4D) at 643 kN lateral load.

For lateral load 898 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00826 \text{ m}$$

Table I.28 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 898 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	1.22E-09	6.76E-06	3.18	2.89E-08	6.79E-06	3.17
10%	6.76E-06	4.90E-09	6.76E-06	3.18	1.23E-07	6.88E-06	3.15
15%	6.76E-06	1.00E-08	6.77E-06	3.17	2.92E-07	7.05E-06	3.11
20%	6.76E-06	1.69E-08	6.78E-06	3.17	5.48E-07	7.31E-06	3.06
25%	6.76E-06	5.63E-09	6.77E-06	3.18	9.51E-07	7.71E-06	2.97
30%	6.76E-06	2.25E-10	6.76E-06	3.18	1.53E-06	8.29E-06	2.87
35%	6.76E-06	1.32E-08	6.77E-06	3.17	2.36E-06	9.12E-06	2.74
40%	6.76E-06	6.00E-08	6.82E-06	3.16	3.53E-06	1.03E-05	2.57
45%	6.76E-06	1.76E-07	6.94E-06	3.14	5.15E-06	1.19E-05	2.39
50%	6.76E-06	4.10E-07	7.17E-06	3.08	7.54E-06	1.43E-05	2.18

Table I.29 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 898 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	7.22E-09	6.77E-06	3.18	2.10E-08	6.78E-06	3.17
10%	6.76E-06	3.06E-08	6.79E-06	3.17	8.41E-08	6.84E-06	3.16
15%	6.76E-06	6.76E-08	6.83E-06	3.16	1.98E-07	6.96E-06	3.13
20%	6.76E-06	1.23E-07	6.88E-06	3.15	3.60E-07	7.12E-06	3.10
25%	6.76E-06	1.98E-07	6.96E-06	3.13	5.78E-07	7.34E-06	3.05
30%	6.76E-06	2.86E-07	7.05E-06	3.11	8.74E-07	7.63E-06	2.99
35%	6.76E-06	3.84E-07	7.14E-06	3.09	1.27E-06	8.03E-06	2.92
40%	6.76E-06	5.18E-07	7.28E-06	3.06	1.76E-06	8.52E-06	2.83
45%	6.76E-06	6.64E-07	7.42E-06	3.03	2.42E-06	9.18E-06	2.73
50%	6.76E-06	8.28E-07	7.59E-06	3.00	3.26E-06	1.00E-05	2.61

Table I.30 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 898 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	3.18	0.00E+00	6.76E-06	3.18
10%	6.76E-06	2.50E-11	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
15%	6.76E-06	2.50E-11	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
20%	6.76E-06	2.50E-11	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
25%	6.76E-06	1.00E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
30%	6.76E-06	1.00E-10	6.76E-06	3.18	4.00E-10	6.76E-06	3.18
35%	6.76E-06	2.25E-10	6.76E-06	3.18	6.25E-10	6.76E-06	3.18
40%	6.76E-06	2.25E-10	6.76E-06	3.18	1.22E-09	6.76E-06	3.18
45%	6.76E-06	2.25E-10	6.76E-06	3.18	2.02E-09	6.76E-06	3.18
50%	6.76E-06	2.25E-10	6.76E-06	3.18	3.02E-09	6.76E-06	3.18

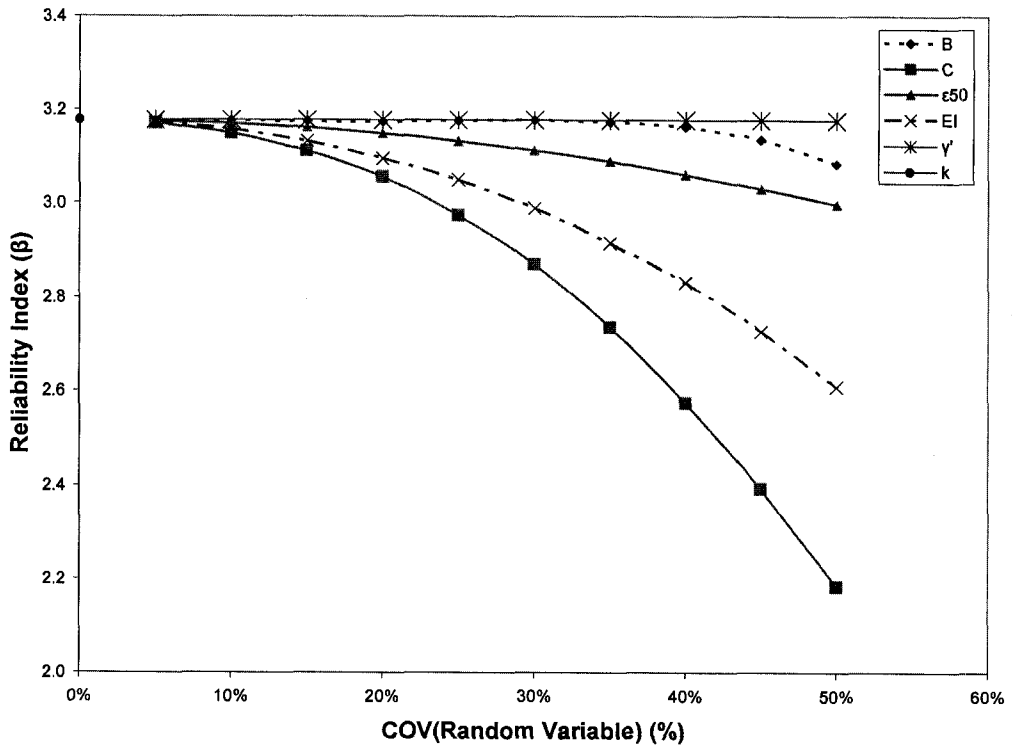

Fig. I.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (4D) at 898 kN lateral load.

For lateral load 1055 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00705 \text{ m}$$

Table I.31 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 1055 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	6.25E-10	6.76E-06	2.71	6.50E-08	6.83E-06	2.70
10%	6.76E-06	2.50E-09	6.76E-06	2.71	2.65E-07	7.03E-06	2.66
15%	6.76E-06	5.63E-09	6.77E-06	2.71	6.08E-07	7.37E-06	2.60
20%	6.76E-06	1.10E-08	6.77E-06	2.71	1.14E-06	7.90E-06	2.51
25%	6.76E-06	2.50E-11	6.76E-06	2.71	1.89E-06	8.65E-06	2.40
30%	6.76E-06	1.96E-08	6.78E-06	2.71	3.01E-06	9.77E-06	2.26
35%	6.76E-06	9.61E-08	6.86E-06	2.69	4.60E-06	1.14E-05	2.09
40%	6.76E-06	2.65E-07	7.03E-06	2.66	6.86E-06	1.36E-05	1.91
45%	6.76E-06	6.48E-07	7.41E-06	2.59	1.01E-05	1.69E-05	1.71
50%	6.76E-06	1.43E-06	8.19E-06	2.46	1.47E-05	2.15E-05	1.52

Table I.32 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1055 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	1.10E-08	6.77E-06	2.71	3.61E-08	6.80E-06	2.70
10%	6.76E-06	4.62E-08	6.81E-06	2.70	1.44E-07	6.90E-06	2.68
15%	6.76E-06	1.02E-07	6.86E-06	2.69	3.31E-07	7.09E-06	2.65
20%	6.76E-06	1.81E-07	6.94E-06	2.68	6.01E-07	7.36E-06	2.60
25%	6.76E-06	2.86E-07	7.05E-06	2.66	9.70E-07	7.73E-06	2.54
30%	6.76E-06	4.10E-07	7.17E-06	2.63	1.46E-06	8.22E-06	2.46
35%	6.76E-06	5.48E-07	7.31E-06	2.61	2.12E-06	8.88E-06	2.37
40%	6.76E-06	7.23E-07	7.48E-06	2.58	2.96E-06	9.72E-06	2.26
45%	6.76E-06	9.51E-07	7.71E-06	2.54	4.08E-06	1.08E-05	2.14
50%	6.76E-06	1.18E-06	7.94E-06	2.50	5.55E-06	1.23E-05	2.01

Table I.33 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 1055 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
10%	6.76E-06	2.50E-11	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
15%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
20%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
25%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
30%	6.76E-06	2.25E-10	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
35%	6.76E-06	4.00E-10	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
40%	6.76E-06	4.00E-10	6.76E-06	2.71	2.25E-10	6.76E-06	2.71
45%	6.76E-06	4.00E-10	6.76E-06	2.71	9.00E-10	6.76E-06	2.71
50%	6.76E-06	6.25E-10	6.76E-06	2.71	2.02E-09	6.76E-06	2.71

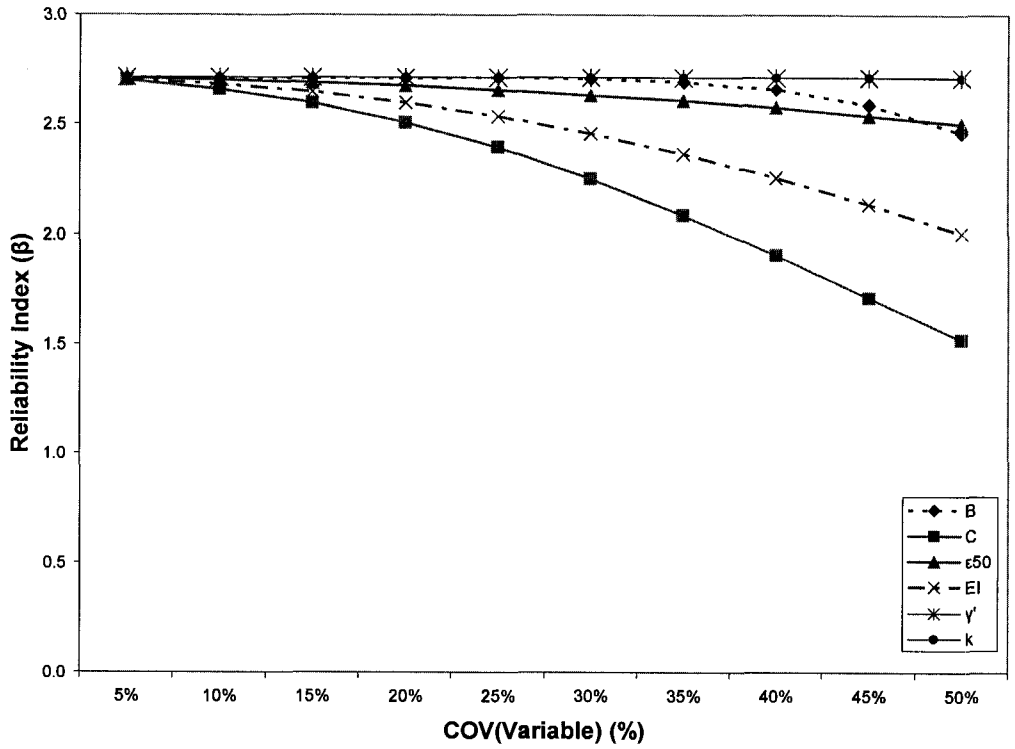

Fig. I.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (4D) at 1055 kN lateral load.

For lateral load 1270 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00503 \text{ m}$$

Table I.34 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 1270 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	1.93	1.52E-07	6.91E-06	1.91
10%	6.76E-06	2.25E-10	6.76E-06	1.93	6.16E-07	7.38E-06	1.85
15%	6.76E-06	6.25E-10	6.76E-06	1.93	1.45E-06	8.21E-06	1.76
20%	6.76E-06	1.22E-09	6.76E-06	1.93	2.64E-06	9.40E-06	1.64
25%	6.76E-06	2.89E-08	6.79E-06	1.93	4.58E-06	1.13E-05	1.49
30%	6.76E-06	1.72E-07	6.93E-06	1.91	7.24E-06	1.40E-05	1.34
35%	6.76E-06	5.40E-07	7.30E-06	1.86	1.07E-05	1.75E-05	1.20
40%	6.76E-06	1.25E-06	8.01E-06	1.78	1.60E-05	2.28E-05	1.05
45%	6.76E-06	3.17E-06	9.93E-06	1.60	2.38E-05	3.06E-05	0.91
50%	6.76E-06	1.36E-05	2.03E-05	1.12	3.66E-05	4.34E-05	0.76

Table I.35 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1270 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	1.82E-08	6.78E-06	1.93	6.76E-08	6.83E-06	1.93
10%	6.76E-06	7.29E-08	6.83E-06	1.92	2.70E-07	7.03E-06	1.90
15%	6.76E-06	1.64E-07	6.92E-06	1.91	6.24E-07	7.38E-06	1.85
20%	6.76E-06	2.86E-07	7.05E-06	1.89	1.13E-06	7.89E-06	1.79
25%	6.76E-06	4.83E-07	7.24E-06	1.87	1.86E-06	8.62E-06	1.71
30%	6.76E-06	6.89E-07	7.45E-06	1.84	2.81E-06	9.57E-06	1.63
35%	6.76E-06	9.31E-07	7.69E-06	1.81	4.00E-06	1.08E-05	1.53
40%	6.76E-06	1.20E-06	7.96E-06	1.78	5.64E-06	1.24E-05	1.43
45%	6.76E-06	1.53E-06	8.29E-06	1.75	7.81E-06	1.46E-05	1.32
50%	6.76E-06	1.86E-06	8.62E-06	1.71	1.06E-05	1.74E-05	1.21

Table I.36 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 1270 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
10%	6.76E-06	2.50E-11	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
15%	6.76E-06	1.00E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
20%	6.76E-06	2.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
25%	6.76E-06	4.00E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
30%	6.76E-06	6.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
35%	6.76E-06	6.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
40%	6.76E-06	9.00E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
45%	6.76E-06	1.23E-09	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
50%	6.76E-06	1.23E-09	6.76E-06	1.93	1.00E-10	6.76E-06	1.93

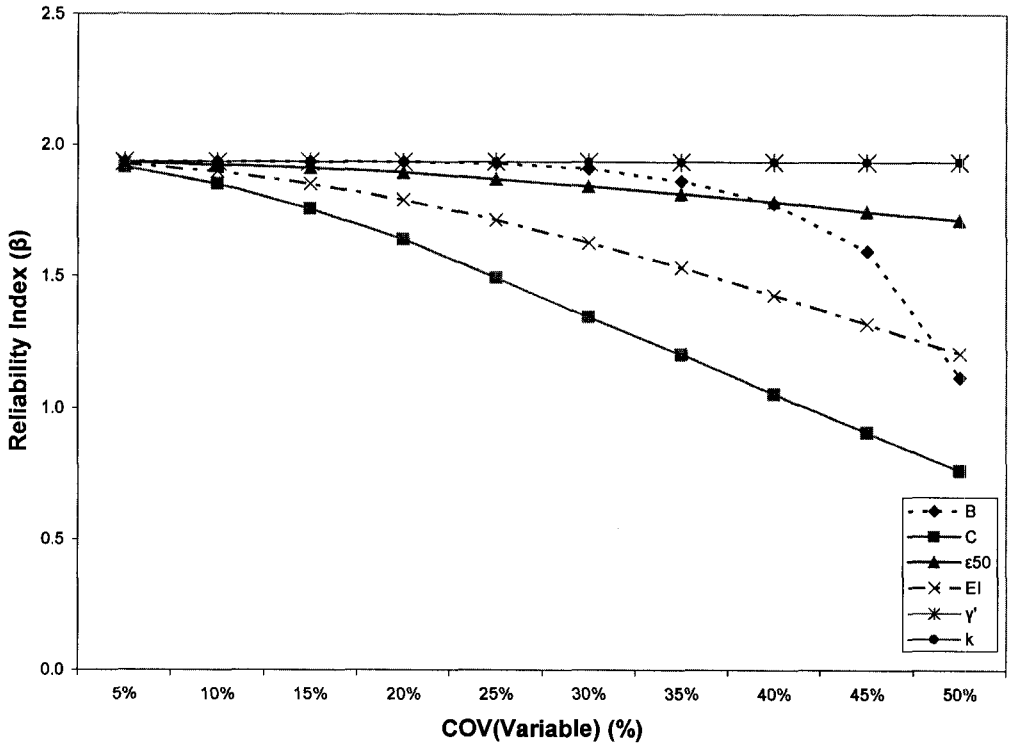

Fig. I.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (4D) at 1270 kN lateral load.

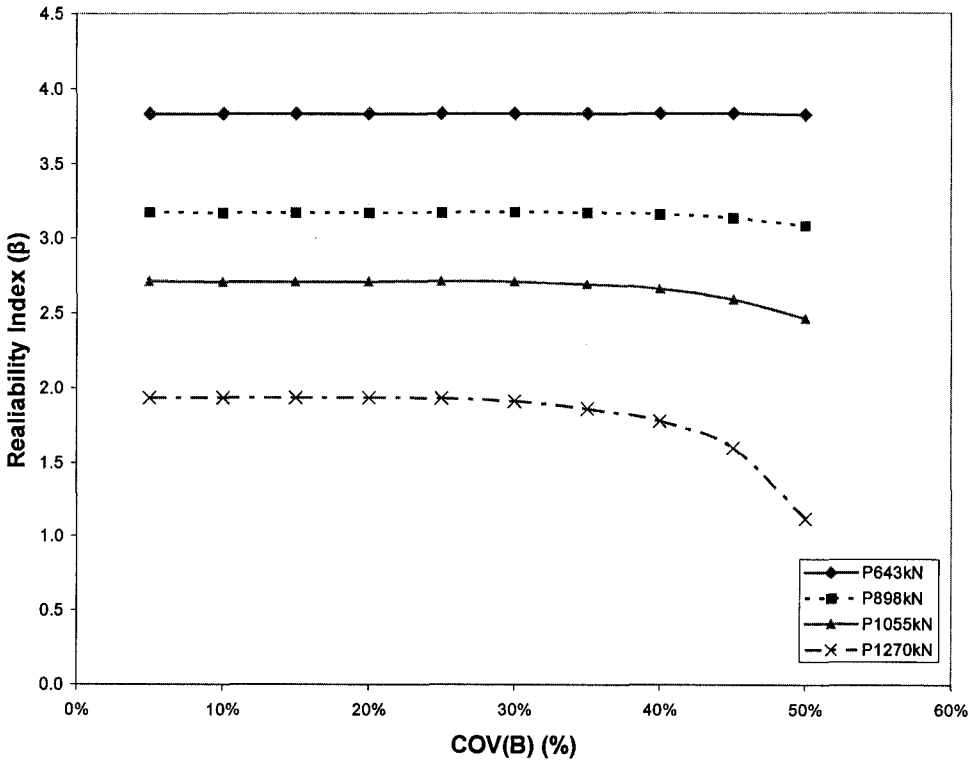

Fig. I.17 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'B'.

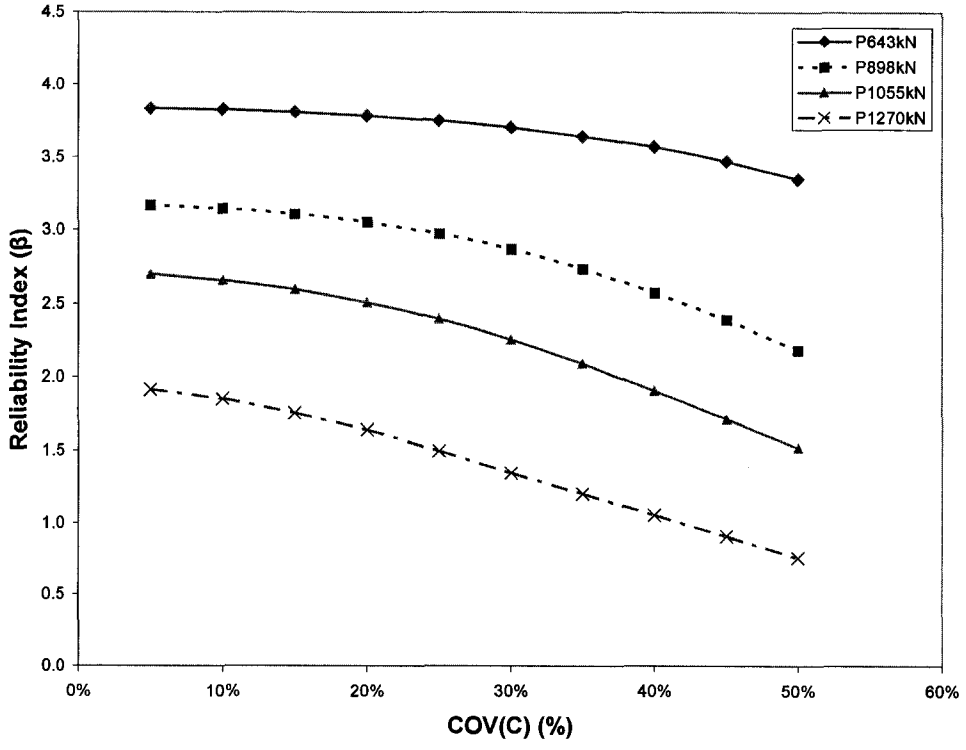

Fig. I.18 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'C'.

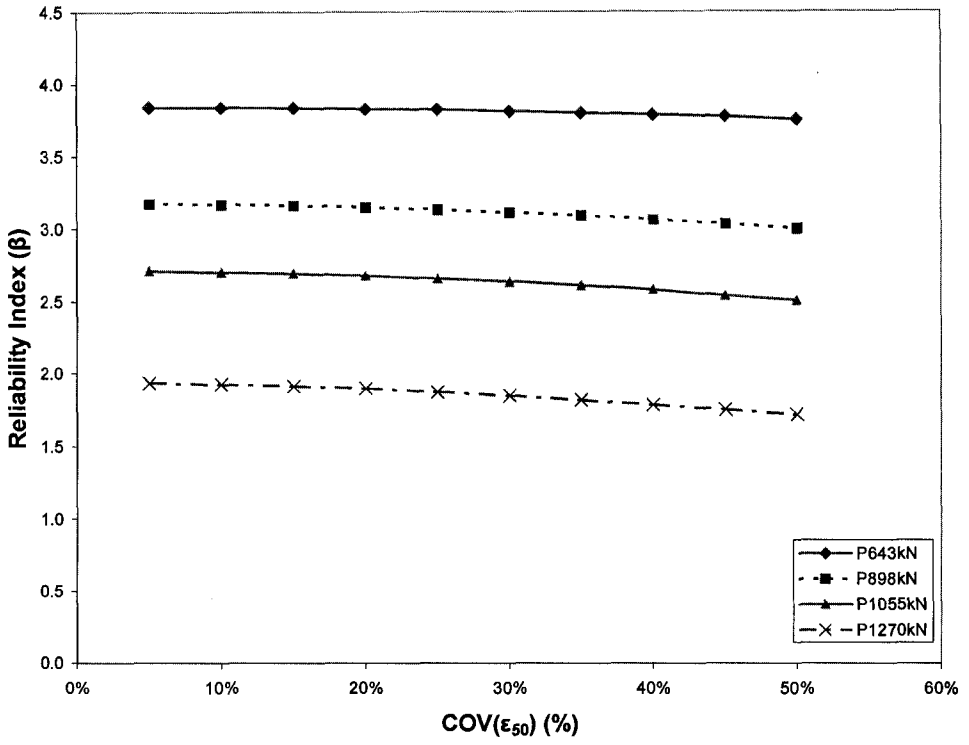

Fig. I.19 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}'.

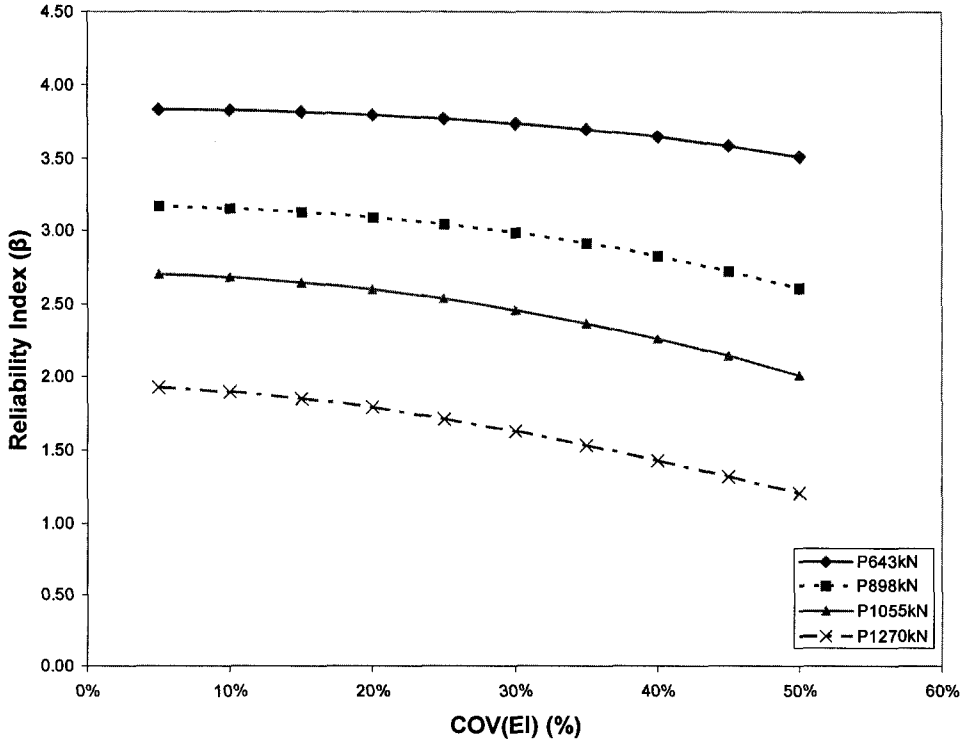

Fig. I.20 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'EI'.

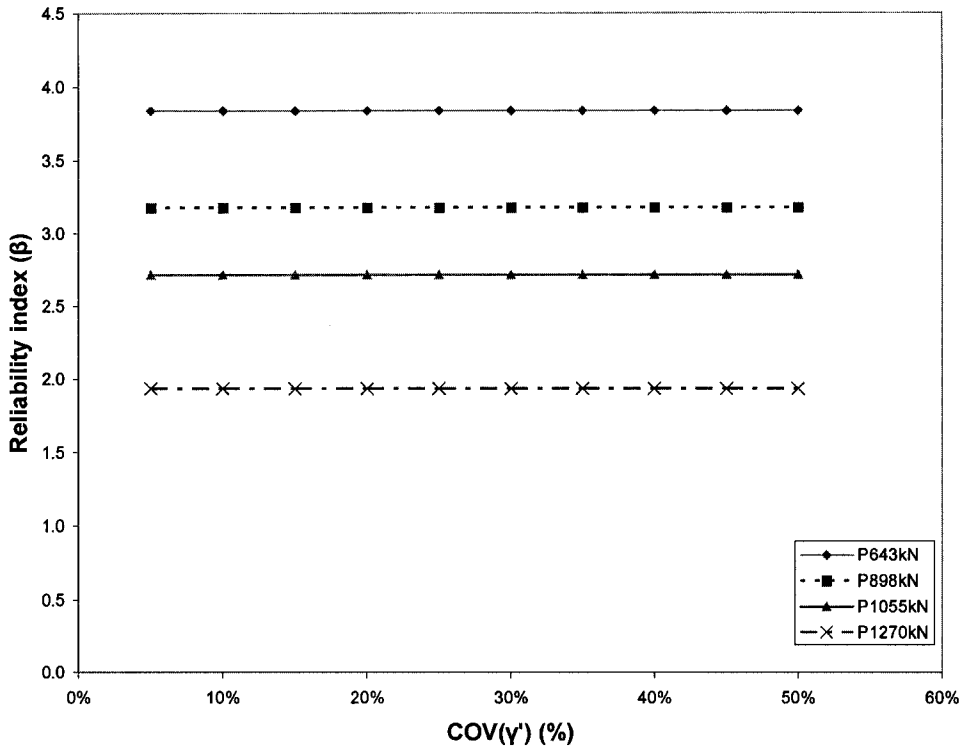

Fig. I.21 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'γ".

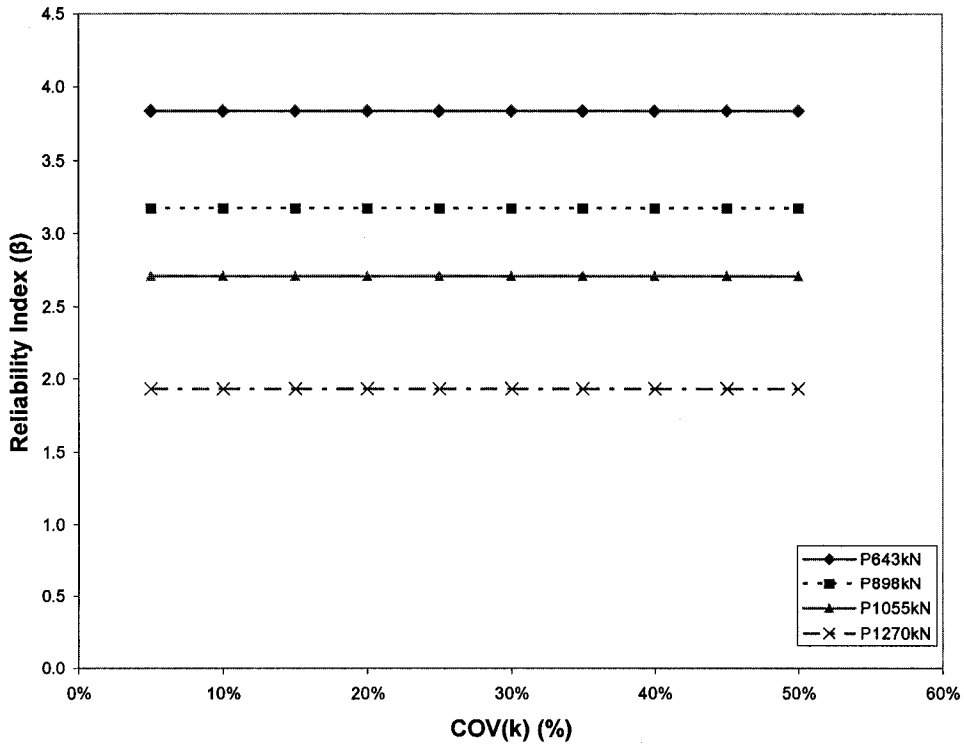

Fig. I.22 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (4D) and with varying 'k'.

I.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 643 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 796.5 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table I.37 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 643 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) (kN-m)^2	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)
5%	31969.44	0.000225	31969.440	4.45	0.0009	31969.441	4.45
10%	31969.44	0.0009	31969.441	4.45	0.001225	31969.441	4.45
15%	31969.44	0.0025	31969.443	4.45	0.0009	31969.441	4.45
20%	31969.44	0.004225	31969.444	4.45	0.0121	31969.452	4.45
25%	31969.44	0.00225	31969.442	4.45	0.009	31969.449	4.45
30%	31969.44	0.0081	31969.448	4.45	0.038025	31969.478	4.45
35%	31969.44	0.011025	31969.451	4.45	0.0576	31969.498	4.45
40%	31969.44	0.0225	31969.463	4.45	0.087025	31969.527	4.45
45%	31969.44	0.055225	31969.495	4.45	0.1444	31969.584	4.45
50%	31969.44	0.156025	31969.596	4.45	0.8836	31970.324	4.45

Table I.38 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 643 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0004	31969.440	4.45	0	31969.440	4.45
10%	31969.44	0.001225	31969.441	4.45	0	31969.440	4.45
15%	31969.44	0.0016	31969.442	4.45	0	31969.440	4.45
20%	31969.44	0.002025	31969.442	4.45	2.5E-05	31969.440	4.45
25%	31969.44	0.00064	31969.441	4.45	0	31969.440	4.45
30%	31969.44	1E-04	31969.440	4.45	2.5E-05	31969.440	4.45
35%	31969.44	0.000225	31969.440	4.45	0.0001	31969.440	4.45
40%	31969.44	0.003025	31969.443	4.45	0.000225	31969.440	4.45
45%	31969.44	0.007225	31969.447	4.45	0.0009	31969.441	4.45
50%	31969.44	0.013225	31969.453	4.45	0.0016	31969.442	4.45

Table I.39 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 643 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.440	4.45	0.0004	31969.440	4.45
10%	31969.44	0.00E+00	31969.440	4.45	0.002025	31969.442	4.45
15%	31969.44	0.00E+00	31969.440	4.45	0.0036	31969.444	4.45
20%	31969.44	0.00E+00	31969.440	4.45	0.0064	31969.446	4.45
25%	31969.44	0.00E+00	31969.440	4.45	0.00289	31969.443	4.45
30%	31969.44	0.00E+00	31969.440	4.45	0.011025	31969.451	4.45
35%	31969.44	0.00E+00	31969.440	4.45	0.0144	31969.454	4.45
40%	31969.44	0.00E+00	31969.440	4.45	0.0196	31969.460	4.45
45%	31969.44	0.00E+00	31969.440	4.45	0.024025	31969.464	4.45
50%	31969.44	2.50E-05	31969.440	4.45	0.0784	31969.518	4.45

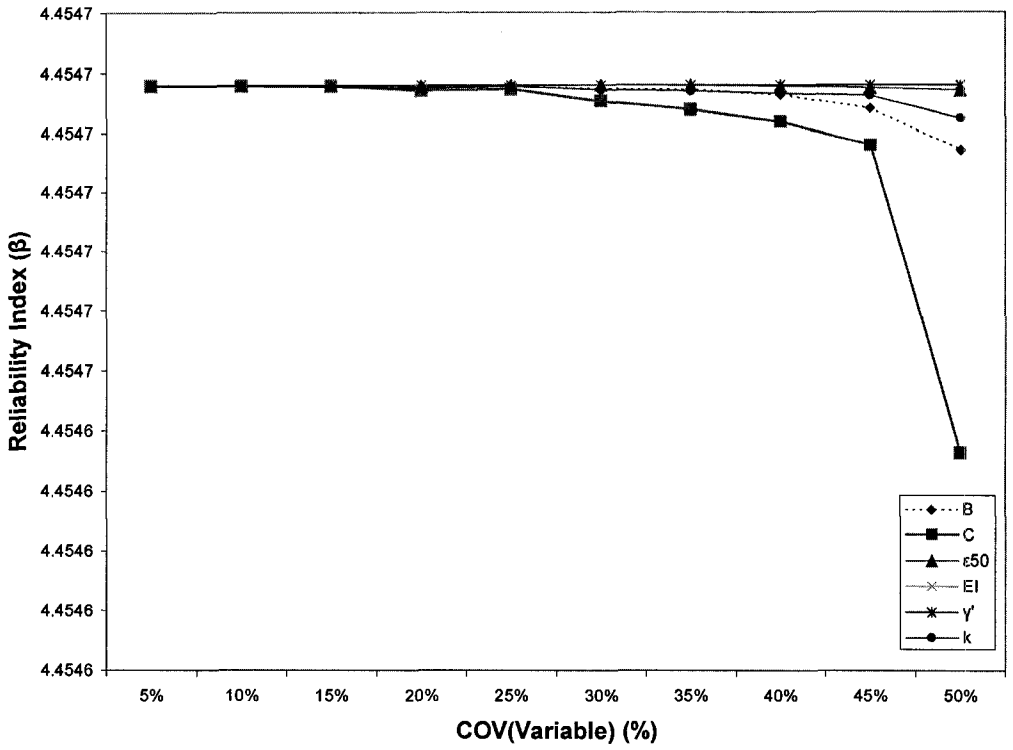

Fig. I.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (4D) at 643 kN lateral load.

For lateral load 898 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 757.7 \text{ kN.m}$$

Table I.40 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 898 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.24	0.0225	31969.46	4.24
10%	31969.44	0.0025	31969.44	4.24	0.0625	31969.50	4.24
15%	31969.44	0.0025	31969.44	4.24	0.09	31969.53	4.24
20%	31969.44	0.01	31969.45	4.24	0.2025	31969.64	4.24
25%	31969.44	0.1225	31969.56	4.24	0.3025	31969.74	4.24
30%	31969.44	0.2025	31969.64	4.24	0.3025	31969.74	4.24
35%	31969.44	0.36	31969.80	4.24	0.4225	31969.86	4.24
40%	31969.44	0.49	31969.93	4.24	0.5625	31970.00	4.24
45%	31969.44	0.7225	31970.16	4.24	0.81	31970.25	4.24
50%	31969.44	0.9025	31970.34	4.24	18.0625	31987.50	4.24

Table I.41 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 898 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.01	31969.45	4.24	0.01	31969.45	4.24
10%	31969.44	0.0225	31969.46	4.24	0.0225	31969.46	4.24
15%	31969.44	0.0625	31969.50	4.24	0.0225	31969.46	4.24
20%	31969.44	0.0625	31969.50	4.24	0.0625	31969.50	4.24
25%	31969.44	0.0625	31969.50	4.24	0.0625	31969.50	4.24
30%	31969.44	0.0625	31969.50	4.24	0.09	31969.53	4.24
35%	31969.44	0.0225	31969.46	4.24	0.09	31969.53	4.24
40%	31969.44	0.01	31969.45	4.24	0.04	31969.48	4.24
45%	31969.44	0.0025	31969.44	4.24	0.04	31969.48	4.24
50%	31969.44	0.01	31969.45	4.24	0.04	31969.48	4.24

Table I.42 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 898 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
10%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
15%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
20%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
25%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
30%	31969.44	0.00E+00	31969.44	4.24	0.01	31969.45	4.24
35%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
40%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24
45%	31969.44	0.00E+00	31969.44	4.24	0	31969.44	4.24
50%	31969.44	0.00E+00	31969.44	4.24	0.0025	31969.44	4.24

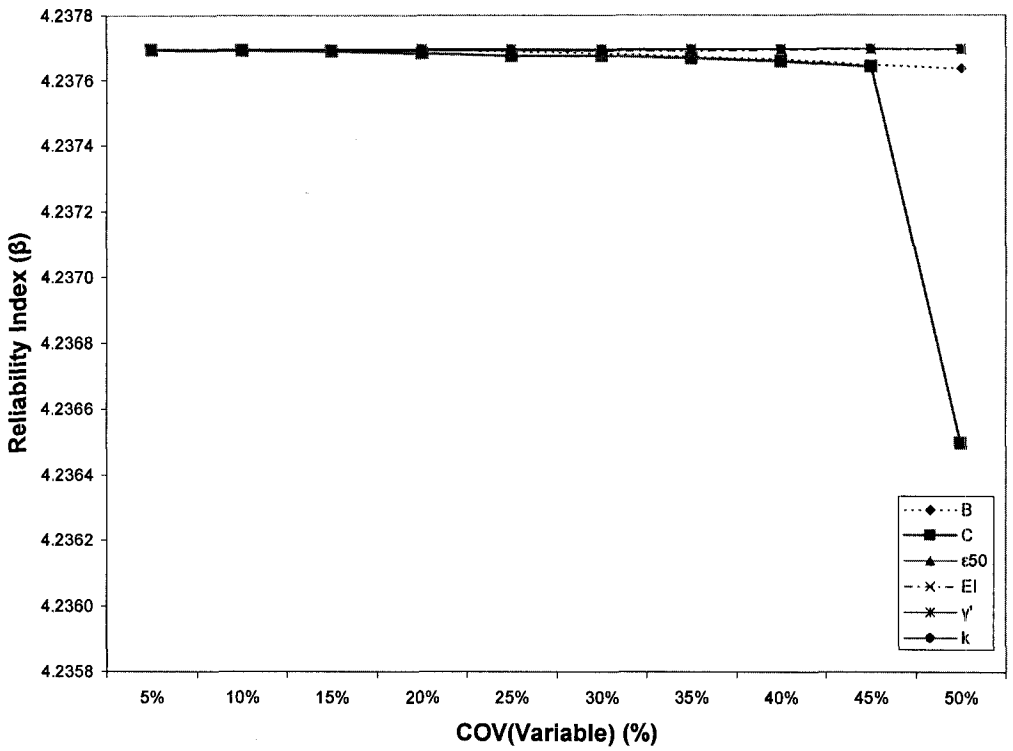

Fig. I.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (4D) at 898 kN lateral load.

For lateral load 1055 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 733.2 \text{ kN.m}$$

Table I.43 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 1055 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.01	31969.45	4.10	0.0625	31969.50	4.10
10%	31969.44	0.04	31969.48	4.10	0.25	31969.69	4.10
15%	31969.44	0.09	31969.53	4.10	0.49	31969.93	4.10
20%	31969.44	0.16	31969.60	4.10	0.64	31970.08	4.10
25%	31969.44	0.2025	31969.64	4.10	0.64	31970.08	4.10
30%	31969.44	0.4225	31969.86	4.10	0.7225	31970.16	4.10
35%	31969.44	0.49	31969.93	4.10	0.7225	31970.16	4.10
40%	31969.44	0.64	31970.08	4.10	7.84	31977.28	4.10
45%	31969.44	1	31970.44	4.10	42.9025	32012.34	4.10
50%	31969.44	1.21	31970.65	4.10	121	32090.44	4.09

Table I.44 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 1055 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.10	0	31969.44	4.10
10%	31969.44	0	31969.44	4.10	0.0025	31969.44	4.10
15%	31969.44	0	31969.44	4.10	0.0025	31969.44	4.10
20%	31969.44	0.01	31969.45	4.10	0.0025	31969.44	4.10
25%	31969.44	0.04	31969.48	4.10	0.01	31969.45	4.10
30%	31969.44	0.04	31969.48	4.10	0.0225	31969.46	4.10
35%	31969.44	0.04	31969.48	4.10	0.04	31969.48	4.10
40%	31969.44	0.0225	31969.46	4.10	0.0625	31969.50	4.10
45%	31969.44	0.01	31969.45	4.10	0.0625	31969.50	4.10
50%	31969.44	0.01	31969.45	4.10	0.0625	31969.50	4.10

Table I.45 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 1055 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	4.10	0	31969.44	4.10
10%	31969.44	0.00E+00	31969.44	4.10	0	31969.44	4.10
15%	31969.44	0.00E+00	31969.44	4.10	0	31969.44	4.10
20%	31969.44	0.00E+00	31969.44	4.10	0	31969.44	4.10
25%	31969.44	0.00E+00	31969.44	4.10	0.01	31969.45	4.10
30%	31969.44	0.00E+00	31969.44	4.10	0.0225	31969.46	4.10
35%	31969.44	0.00E+00	31969.44	4.10	0.04	31969.48	4.10
40%	31969.44	0.00E+00	31969.44	4.10	0.04	31969.48	4.10
45%	31969.44	0.00E+00	31969.44	4.10	0.0225	31969.46	4.10
50%	31969.44	0.00E+00	31969.44	4.10	0.01	31969.45	4.10

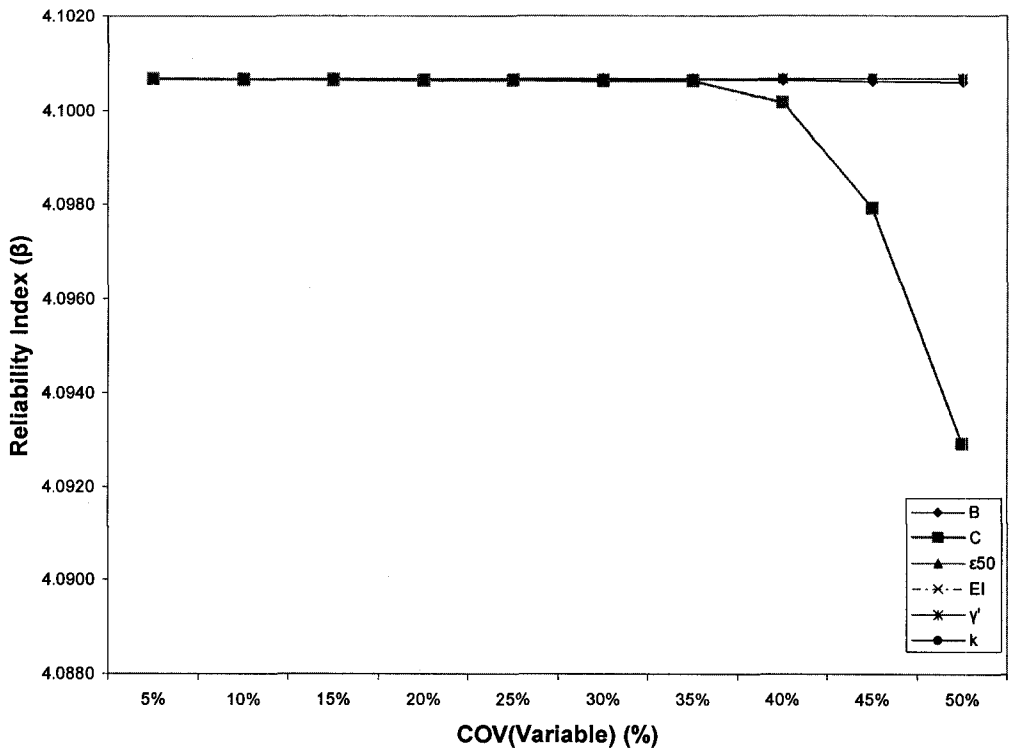

Fig. I.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (4D) at 1055 kN lateral load.

For lateral load 1270 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 699.9 \text{ kN.m}$$

Table I.46 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 1270 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	3.91	0.0225	31969.46	3.91
10%	31969.44	0.0225	31969.46	3.91	0.09	31969.53	3.91
15%	31969.44	0.0625	31969.50	3.91	0.2025	31969.64	3.91
20%	31969.44	0.1225	31969.56	3.91	0.49	31969.93	3.91
25%	31969.44	0.25	31969.69	3.91	0.81	31970.25	3.91
30%	31969.44	0.49	31969.93	3.91	10.89	31980.33	3.91
35%	31969.44	0.64	31970.08	3.91	58.5225	32027.96	3.91
40%	31969.44	1	31970.44	3.91	155.0025	32124.44	3.90
45%	31969.44	11.2225	31980.66	3.91	338.56	32308.00	3.89
50%	31969.44	460.1025	32429.54	3.89	647.7025	32617.14	3.88

Table I.47 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 1270 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.443	3.91	0.0025	31969.443	3.91
10%	31969.44	0.0025	31969.443	3.91	0.01	31969.450	3.91
15%	31969.44	0.01	31969.450	3.91	0.0225	31969.463	3.91
20%	31969.44	0.0225	31969.463	3.91	0.0225	31969.463	3.91
25%	31969.44	0.0225	31969.463	3.91	0.04	31969.480	3.91
30%	31969.44	0.04	31969.480	3.91	0.0625	31969.503	3.91
35%	31969.44	0.1225	31969.563	3.91	0.0625	31969.503	3.91
40%	31969.44	0.25	31969.690	3.91	0.09	31969.530	3.91
45%	31969.44	0.3025	31969.743	3.91	0.1225	31969.563	3.91
50%	31969.44	0.3025	31969.743	3.91	0.16	31969.600	3.91

Table I.48 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 1270 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
10%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
15%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
20%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
25%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
30%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
35%	31969.44	0.00E+00	31969.44	3.91	0	31969.44	3.91
40%	31969.44	2.50E-03	31969.44	3.91	0	31969.44	3.91
45%	31969.44	2.50E-03	31969.44	3.91	0.0025	31969.44	3.91
50%	31969.44	2.50E-03	31969.44	3.91	0.09	31969.53	3.91

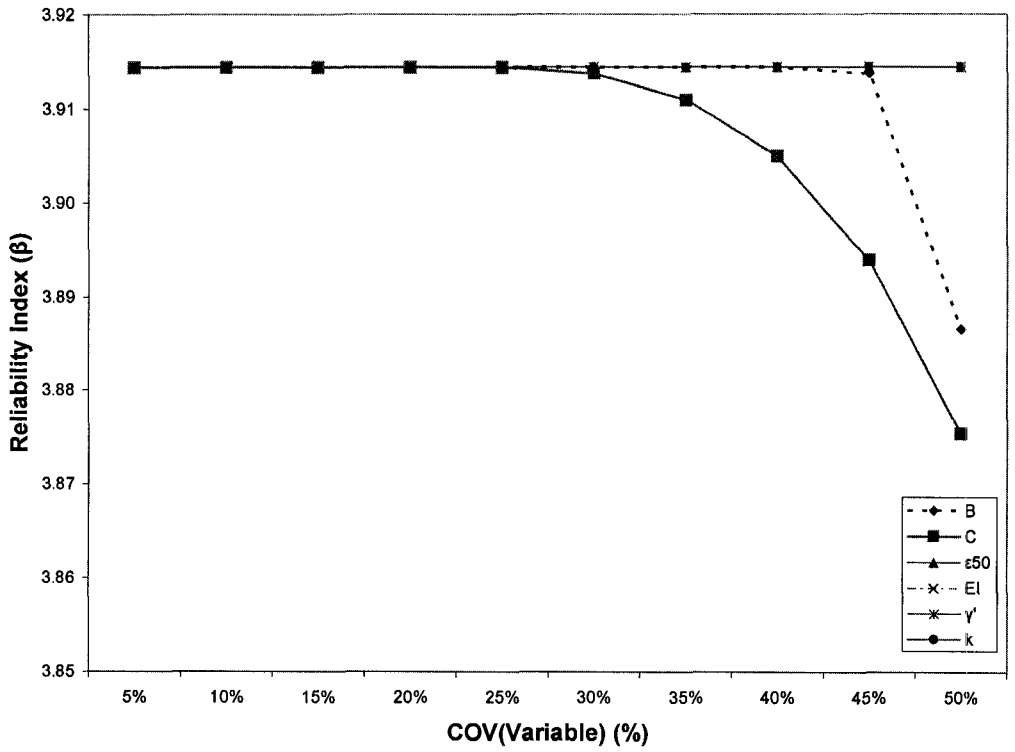

Fig. I.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (4D) at 1270 kN lateral load.

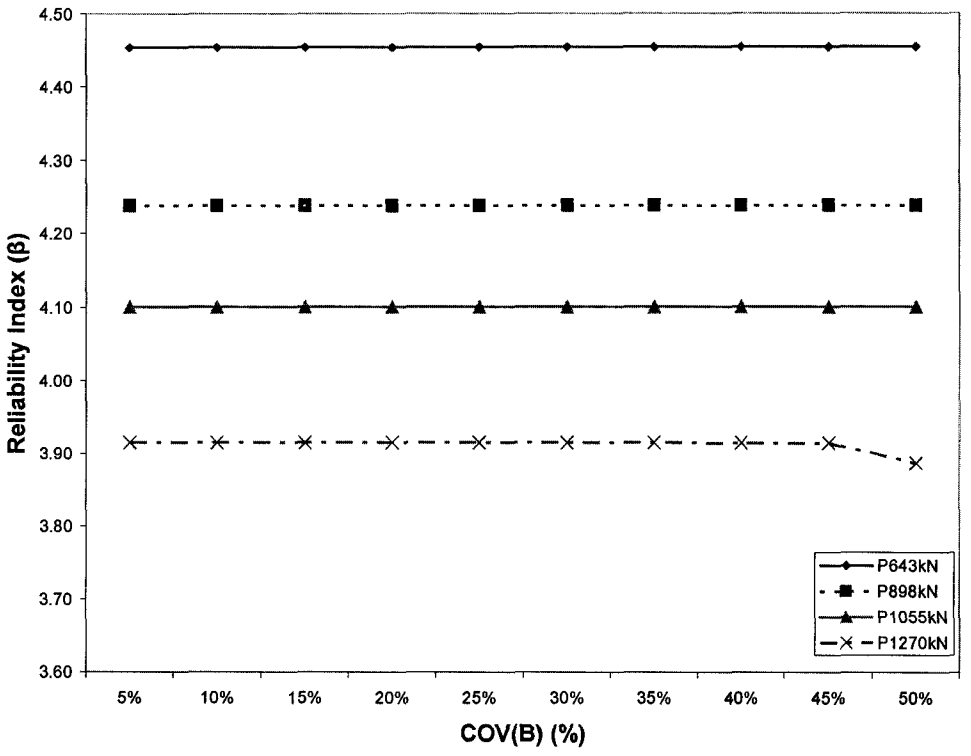

Fig. I.27 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'B'.

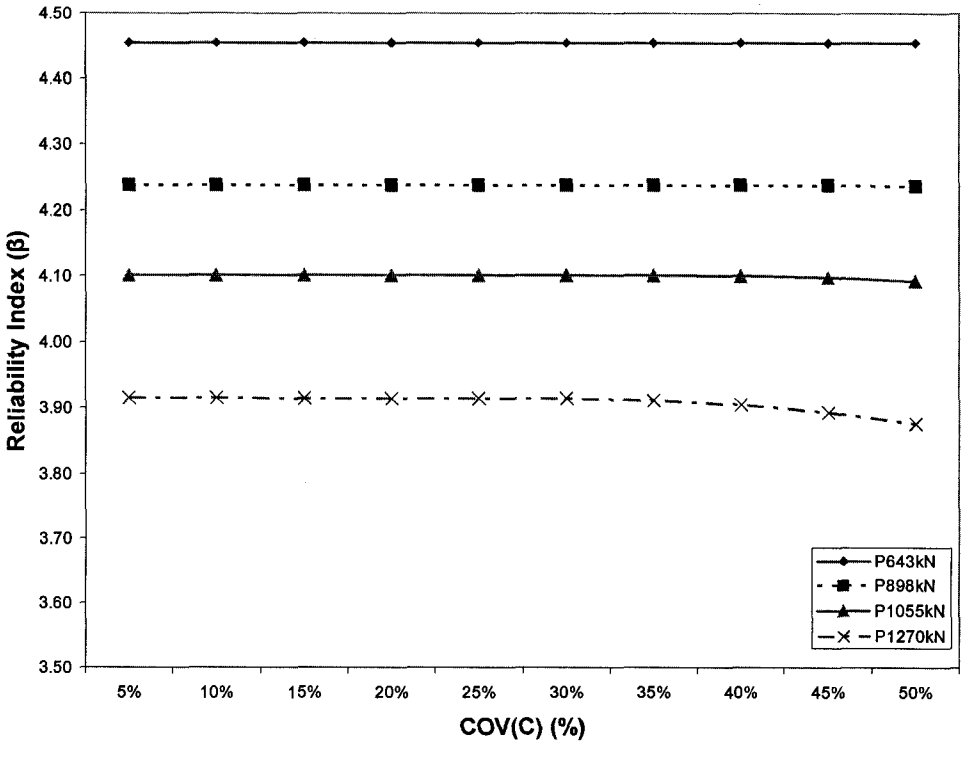

Fig. I.28 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'C'.

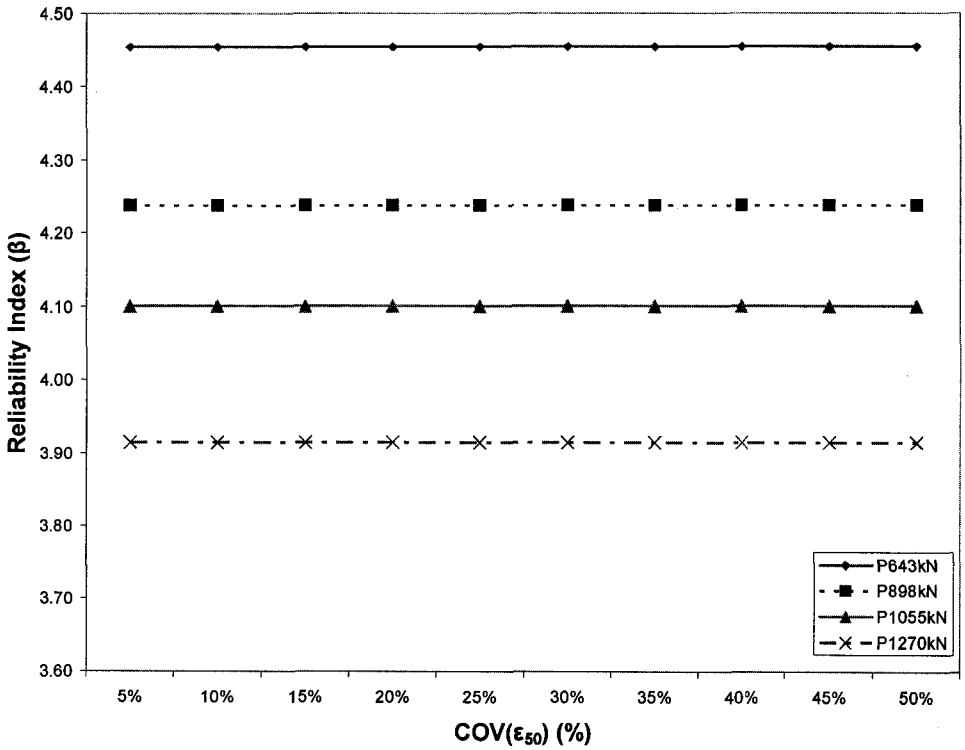

Fig. I.29 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'ε_{50}'.

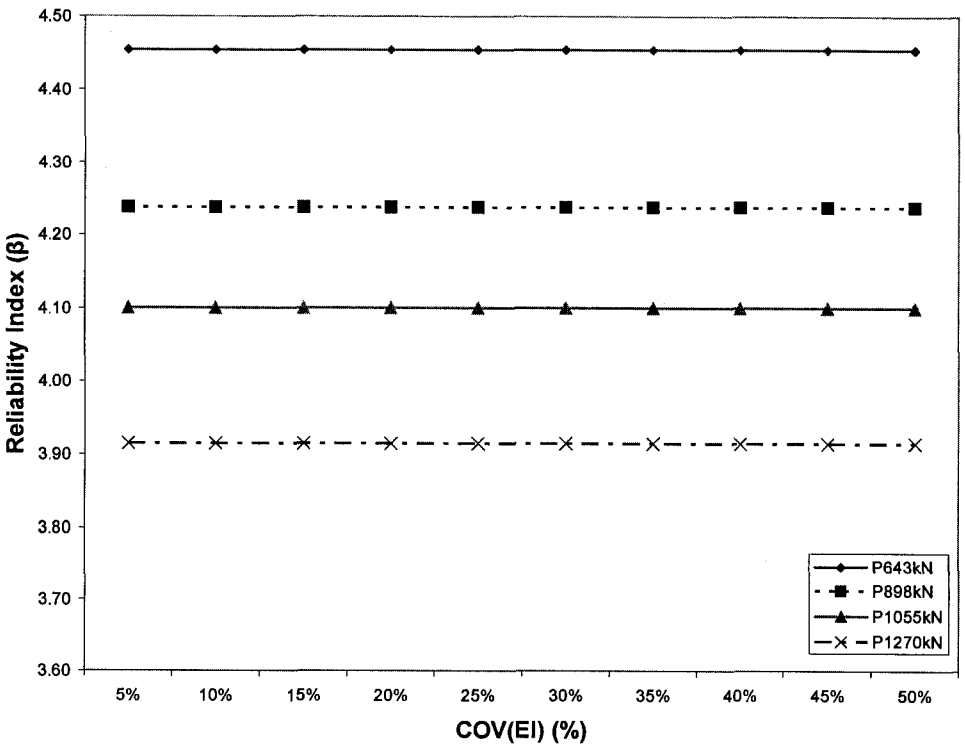

Fig. I.30 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'EI'.

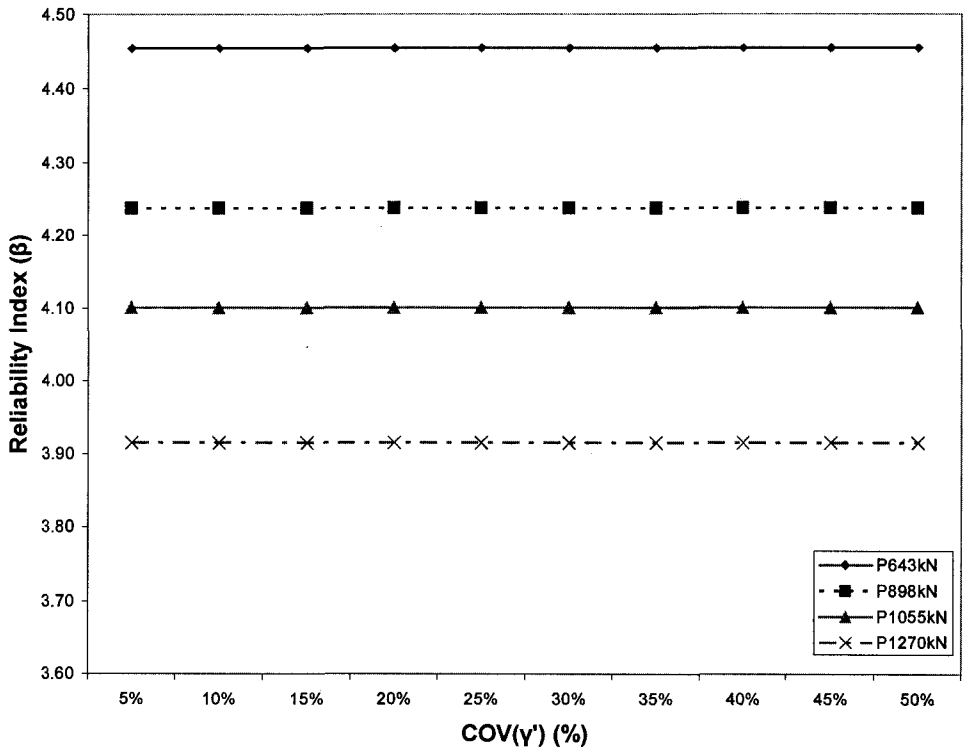

Fig. I.31 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'γ'.

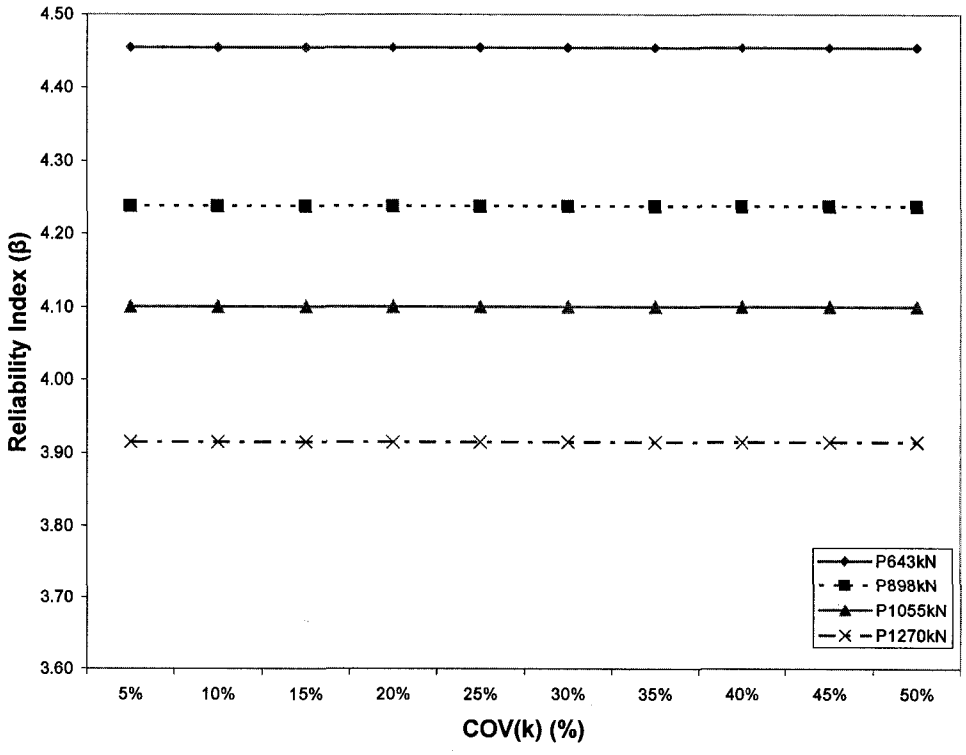

Fig. I.32 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (4D) and with varying 'k'.

APPENDIX J

LATERALLY LOADED FIXED HEAD LONG PILE

(Spacing: 4D)

J.1.1 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (4D) and with 'B' as varying random design variable

Table J.1. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1725 kN and 2138 kN.

			P=1725 kN (180, 190, 210 kN)				P=2138 kN (220, 240, 260 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45%	0.052258	0.2794	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
40%	0.0412902	0.3048	0.00473	79.56	82.97	85.98	0.00749	113.6	120.2	125.8
35%	0.0316128	0.3302	0.00439	76.29	79.47	82.26	0.00673	106.9	112.8	117.6
30%	0.0232258	0.3556	0.00418	74.64	77.7	80.37	0.00626	103.1	108.5	113
25%	0.016129	0.381	0.00404	73.63	76.6	79.2	0.00593	100.6	105.6	110
20%	0.0103226	0.4064	0.0039	72.7	75.62	78.13	0.00565	98.54	103.2	107.4
15%	0.0058064	0.4318	0.00379	71.99	74.84	77.27	0.00545	97.03	101.6	105.6
10%	0.0025806	0.4572	0.00369	71.41	74.2	76.54	0.00527	95.72	100.2	104.1
5%	0.0006452	0.4826	0.00361	70.95	73.67	76.24	0.00512	94.78	99.11	102.9
0%	0	0.508	0.00354	70.61	73.25	76.14	0.005	94.08	98.34	102
5%	0.0006452	0.5334	0.00348	70.33	72.89	76.14	0.00492	93.71	97.88	101.5
10%	0.0025806	0.5588	0.00342	70.1	72.58	76.23	0.00482	93.2	97.32	100.8
15%	0.0058064	0.5842	0.00337	69.88	72.3	76.37	0.00474	92.76	96.81	100.2
20%	0.0103226	0.6096	0.00332	69.69	72.04	76.57	0.00466	92.38	96.34	99.68
25%	0.016129	0.635	0.00329	69.65	71.97	76.52	0.0046	92.2	96.12	99.4
30%	0.0232258	0.6604	0.00328	69.98	72.33	75.83	0.00459	92.51	96.45	99.74
35%	0.0316128	0.6858	0.00328	70.33	72.71	75.22	0.00457	92.82	96.77	100.1
40%	0.0412902	0.7112	0.00327	70.71	73.11	75.03	0.00456	93.12	97.09	100.4
45%	0.052258	0.7366	#	#	#	#	#	#	#	#
50%	0.064516	0.762	#	#	#	#	#	#	#	#

Table J.2 Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 2387 kN and 2671 kN.

			P=2387 kN (240, 270, 290 kN)				P=2671 kN (270, 300, 320 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45%	0.052258	0.2794	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
40%	0.0412902	0.3048	0.0105	141.4	152	161.4	Failed	Failed	Failed	Failed
35%	0.0316128	0.3302	0.00869	128.5	136.9	144	0.0136	164.3	178.6	191.6
30%	0.0232258	0.3556	0.00793	122.6	130.3	136.7	0.0106	147.7	159.2	169.1
25%	0.016129	0.381	0.00741	118.7	125.9	131.7	0.00953	141.5	151.5	159.9
20%	0.0103226	0.4064	0.00699	115.7	122.4	127.8	0.00886	137	146.2	154
15%	0.0058064	0.4318	0.00668	113.6	119.9	125	0.00837	133.8	142.4	149.7
10%	0.0025806	0.4572	0.00642	111.8	117.6	122.6	0.00796	131.2	139.3	146
5%	0.0006452	0.4826	0.00619	110.3	115.9	120.7	0.00763	129.1	136.9	143
0%	0	0.508	0.00603	109.4	114.7	119.5	0.00737	127.6	135	140.9
5%	0.0006452	0.5334	0.00588	108.5	113.7	118.3	0.00717	126.5	133.5	139.2
10%	0.0025806	0.5588	0.00576	107.8	112.9	117.3	0.00698	125.4	132.1	137.7
15%	0.0058064	0.5842	0.00565	107.2	112.2	116.6	0.00681	124.5	130.9	136.4
20%	0.0103226	0.6096	0.00555	106.6	111.6	115.9	0.00668	123.9	130.1	135.5
25%	0.016129	0.635	0.00549	106.5	111.4	115.7	0.00658	123.4	129.5	134.8
30%	0.0232258	0.6604	0.00547	106.9	111.8	116	0.00655	123.7	129.8	135
35%	0.0316128	0.6858	0.00545	107.1	112.1	116.3	0.00652	124	130	135.4
40%	0.0412902	0.7112	0.00543	107.4	112.4	116.7	#	#	#	#
45%	0.052258	0.7366	#	#	#	#	#	#	#	#
50%	0.064516	0.762	#	#	#	#	#	#	#	#

Table J.3(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1725 kN and 2138 kN.

		P=1725 kN		P=2138 kN	
COV(B) (%)	Var (B) (m)2	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.0006452	4.225E-09	1.836%	1E-08	2.000%
10%	0.0025806	1.823E-08	3.814%	5.063E-08	4.500%
15%	0.0058064	4.41E-08	5.932%	1.26E-07	7.100%
20%	0.0103226	8.41E-08	8.192%	2.45E-07	9.900%
25%	0.016129	1.406E-07	10.593%	4.422E-07	13.300%
30%	0.0232258	2.025E-07	12.712%	6.972E-07	16.700%
35%	0.0316128	3.08E-07	15.678%	1.166E-06	21.600%
40%	0.0412902	5.329E-07	20.621%	2.146E-06	29.300%

Table J.3(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (4D) and with varying 'B' and lateral load 2387 kN and 2671 kN.

		P=2387 kN		P=2671 kN	
COV(B) (%)	Var (B) (m)2	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.0006452	2.403E-08	2.570%	5.29E-08	3.121%
10%	0.0025806	1.089E-07	5.473%	2.401E-07	6.649%
15%	0.0058064	2.652E-07	8.541%	6.084E-07	10.583%
20%	0.0103226	5.184E-07	11.940%	1.188E-06	14.790%
25%	0.016129	9.216E-07	15.920%	2.176E-06	20.014%
30%	0.0232258	1.513E-06	20.398%	4.101E-06	27.476%
35%	0.0316128	2.624E-06	26.866%	1.253E-05	48.033%
40%	0.0412902	6.426E-06	42.040%	Failed	Failed

Table J.4(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 1725 kN.

		P=1725 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.0961	0.1521	0.0025	0.44%	0.53%	0.07%
10%	0.0025806	0.429025	0.6561	0.024025	0.93%	1.11%	0.20%
15%	0.0058064	1.113025	1.6129	0.2025	1.49%	1.73%	0.59%
20%	0.0103226	2.265025	3.2041	0.6084	2.13%	2.44%	1.02%
25%	0.016129	3.9601	5.359225	0.71824	2.82%	3.16%	1.11%
30%	0.0232258	5.4289	7.209225	5.1529	3.30%	3.67%	2.98%
35%	0.0316128	8.8804	11.4244	12.3904	4.22%	4.61%	4.62%
40%	0.0412902	19.580625	24.3049	29.975625	6.27%	6.73%	7.19%

Table J.4(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 2138 kN.

		P=2138 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.286225	0.378225	0.49	0.57%	0.63%	0.69%
10%	0.0025806	1.5876	2.0736	2.7225	1.34%	1.46%	1.62%
15%	0.0058064	4.558225	5.736025	7.29	2.27%	2.44%	2.65%
20%	0.0103226	9.4864	11.7649	14.8996	3.27%	3.49%	3.78%
25%	0.016129	17.64	22.4676	28.09	4.46%	4.82%	5.20%
30%	0.0232258	28.037025	36.300625	43.9569	5.63%	6.13%	6.50%
35%	0.0316128	49.5616	64.240225	76.5625	7.48%	8.15%	8.58%
40%	0.0412902	104.8576	133.51803	161.29	10.88%	11.75%	12.45%

Table J.4(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 2387 kN.

		P=2387 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	0.81	1.21	1.44	0.82%	0.96%	1.00%
10%	0.0025806	4	5.5225	7.0225	1.83%	2.05%	2.22%
15%	0.0058064	10.24	14.8225	17.64	2.93%	3.36%	3.51%
20%	0.0103226	20.7025	29.16	35.4025	4.16%	4.71%	4.98%
25%	0.016129	37.21	52.5625	64	5.58%	6.32%	6.69%
30%	0.0232258	61.6225	85.5625	107.1225	7.18%	8.06%	8.66%
35%	0.0316128	114.49	153.76	191.8225	9.78%	10.81%	11.59%
40%	0.0412902	289	392.04	499.5225	15.54%	17.26%	18.70%

Table J.4(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and lateral load 2671 kN.

		P=2671 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.0006452	1.69	2.89	3.61	1.02%	1.26%	1.35%
10%	0.0025806	8.41	12.96	17.2225	2.27%	2.67%	2.95%
15%	0.0058064	21.6225	33.0625	44.2225	3.64%	4.26%	4.72%
20%	0.0103226	42.9025	64.8025	85.5625	5.13%	5.96%	6.56%
25%	0.016129	81.9025	121	157.5025	7.09%	8.15%	8.91%
30%	0.0232258	144	216.09	290.7025	9.40%	10.89%	12.10%
35%	0.0316128	406.0225	590.49	789.61	15.79%	18.00%	19.94%
40%	0.0412902	Failed	Failed	Failed	Failed	Failed	Failed

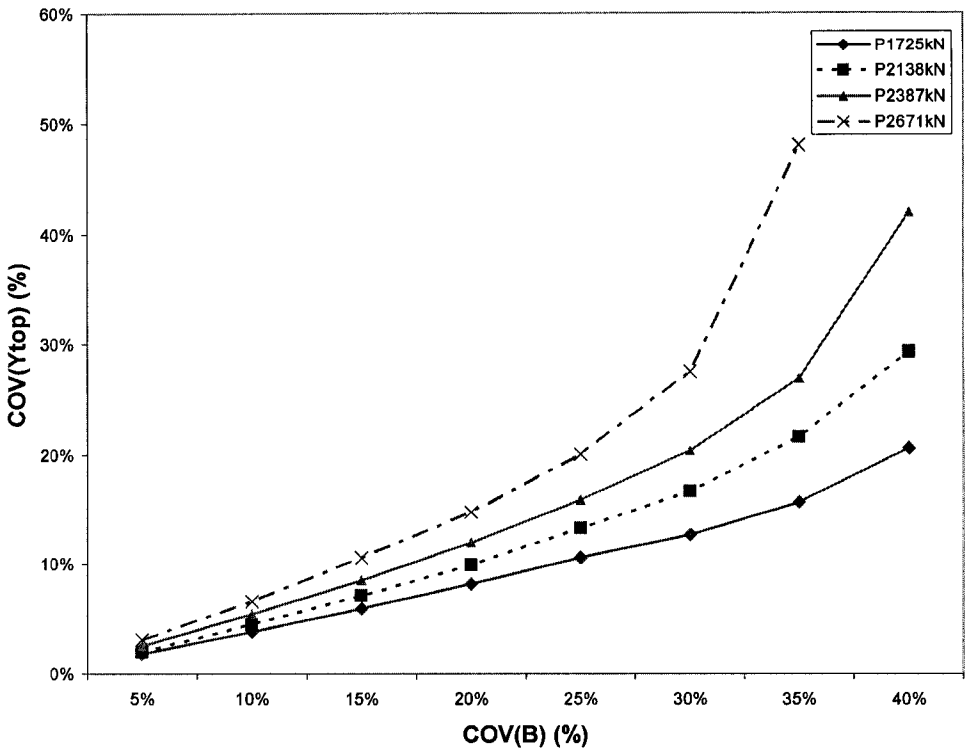

Fig. J.1 COV(Y_{Top}) for varying COV(B) in fixed head long (10T) pile group with spacing (4D).

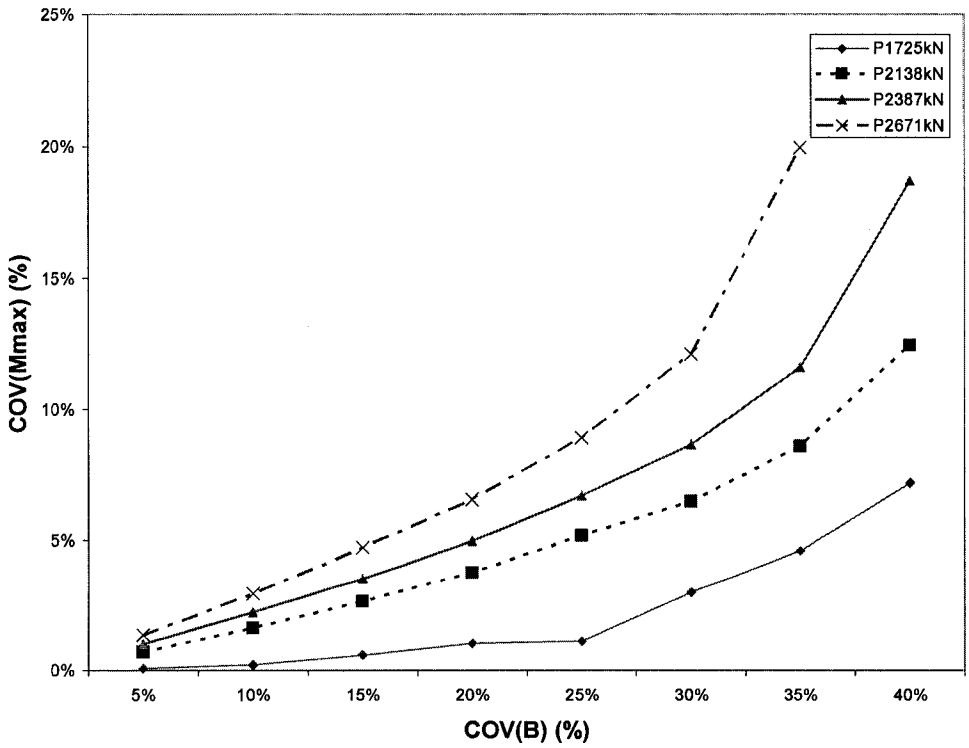

Fig. J.2(a) COV(M_{Max}) for varying COV(B) for pile C in fixed head long pile group with spacing (4D).

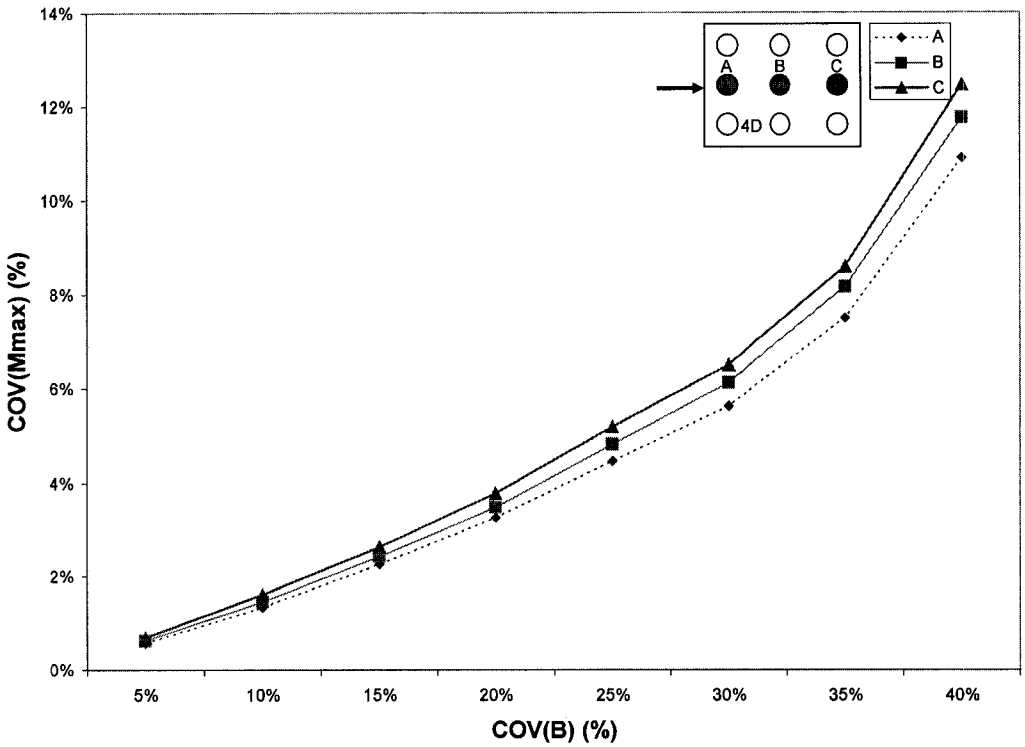

Fig. J.2(b) COV(M_{Max}) for varying COV(B) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (4D) at the optimum lateral load 2138 kN.

J.1.2 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (4D) and with 'C' as varying random design variable

Table J.5. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1725 kN and 2138 kN.

			P=1725 kN (180, 190, 210 kN)				P=2138 kN (220, 240, 260 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5								
45.00%	1139.0625	41.25	0.00663	84.23	91.58	98.16	0.0102	113.6	118.3	128.3
40.00%	900	45	0.00598	83.41	90.07	95.92	0.00902	107.6	117.7	126.6
35.00%	689.0625	48.75	0.00547	82.3	88.29	93.48	0.00813	106.9	116	124.1
30.00%	506.25	52.5	0.00504	80.96	86.27	90.76	0.00744	105.7	114	121.3
25.00%	351.5625	56.25	0.0047	79.5	84.16	87.97	0.00683	104.1	111.6	118.1
20.00%	225	60	0.0044	77.89	81.87	85.29	0.00634	102.3	109	114.8
15.00%	126.5625	63.75	0.00416	76.13	79.67	82.81	0.00592	100.4	106.4	111.2
10.00%	56.25	67.5	0.00393	74.21	77.48	80.33	0.00558	98.42	103.6	108
5.00%	14.0625	71.25	0.00372	72.38	75.35	77.87	0.00527	96.33	100.9	104.9
0.00%	0	75	0.00354	70.61	73.25	76.14	0.005	94.08	98.34	102
5.00%	14.0625	78.75	0.00337	68.87	71.16	76.86	0.00477	92.03	95.94	99.28
10.00%	56.25	82.5	0.00323	67.14	71.12	77.43	0.00455	89.9	93.46	96.4
15.00%	126.5625	86.25	0.00309	65.45	71.7	77.86	0.00435	87.87	91.03	95.91
20.00%	225	90	0.00297	65.67	72.18	78.14	0.00417	85.85	88.62	96.62
25.00%	351.5625	93.75	0.00286	66.26	72.58	78.21	0.004	83.77	89.38	97.24
30.00%	506.25	97.5	0.00277	66.81	72.79	78.32	0.00385	81.81	89.96	97.63
35.00%	689.0625	101.25	0.00269	67.16	72.98	78.46	0.00372	82.2	90.37	97.82
40.00%	900	105	0.00261	67.37	73.15	78.56	0.00359	82.8	90.75	97.83
45.00%	1139.0625	108.75	0.00253	67.57	73.28	78.62	0.00348	83.31	90.91	97.82
50.00%	1406.25	112.5	0.00246	67.74	73.37	78.63	0.00337	83.67	90.98	97.83

Table J.6. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 2387 kN and 2671 kN.

			P=2387 kN (240, 270, 290 kN)				P=2671 kN (270, 300, 320 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5								
45.00%	1139.0625	41.25	0.0133	139.5	147.1	152.9	0.0196	179.2	193.4	205.4
40.00%	900	45	0.0115	129.2	134.2	145.5	0.0157	163.7	173	180.2
35.00%	689.0625	48.75	0.0102	121.7	133.4	143.9	0.0134	150	156.3	166.1
30.00%	506.25	52.5	0.00923	121.3	131.8	140.9	0.0118	138.5	152	164.4
25.00%	351.5625	56.25	0.00844	119.8	129.3	137.6	0.0107	137.9	150.6	161.5
20.00%	225	60	0.00781	118.1	126.8	134.2	0.00974	136.8	147.8	157.4
15.00%	126.5625	63.75	0.00725	116	123.9	130.5	0.00901	134.8	144.9	153.6
10.00%	56.25	67.5	0.00677	113.9	120.9	126.6	0.00838	132.5	141.7	149.4
5.00%	14.0625	71.25	0.00637	111.7	117.7	122.8	0.00784	130.1	138.4	145.2
0.00%	0	75	0.00603	109.4	114.7	119.5	0.00737	127.6	135	140.9
5.00%	14.0625	78.75	0.00572	106.8	111.8	116.1	0.00698	125.1	131.5	137
10.00%	56.25	82.5	0.00545	104.5	109	112.9	0.00662	122.2	128.1	133.2
15.00%	126.5625	86.25	0.00521	102.2	106.4	109.9	0.00632	119.6	125.1	129.8
20.00%	225	90	0.00499	99.98	103.7	107.6	0.00603	116.9	122	126.2
25.00%	351.5625	93.75	0.00478	97.75	101.1	108.4	0.00577	114.5	119.1	122.8
30.00%	506.25	97.5	0.0046	95.56	100.1	109	0.00554	112.1	116.2	121.8
35.00%	689.0625	101.25	0.00443	93.43	100.8	109.5	0.00533	109.7	113.4	122.6
40.00%	900	105	0.00427	91.97	101.3	109.8	0.00514	107.4	113.2	123.2
45.00%	1139.0625	108.75	0.00413	92.65	101.8	109.9	0.00496	105.1	113.8	123.6
50.00%	1406.25	112.5	0.00401	93.15	102	109.9	0.00479	103.8	114.4	123.9

Table J.7(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1725 kN and 2138 kN.

		P=1725 kN		P=2138 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	3.06E-08	4.944%	6.25E-08	5.000%
10.00%	5.63E+01	1.23E-07	9.887%	2.65E-07	10.300%
15.00%	1.27E+02	2.86E-07	15.113%	6.16E-07	15.700%
20.00%	2.25E+02	5.11E-07	20.198%	1.18E-06	21.700%
25.00%	3.52E+02	8.46E-07	25.989%	2.00E-06	28.300%
30.00%	5.06E+02	1.29E-06	32.062%	3.22E-06	35.900%
35.00%	6.89E+02	1.93E-06	39.266%	4.86E-06	44.100%
40.00%	9.00E+02	2.84E-06	47.599%	7.37E-06	54.300%
45.00%	1.14E+03	4.20E-06	57.910%	1.13E-05	67.200%

Table J.7(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (4D) and with varying 'C' and lateral load 2387 kN and 2671 kN.

		P=2387 kN		P=2671 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	1.06E-07	5.390%	1.85E-07	5.834%
10.00%	5.63E+01	4.36E-07	10.945%	7.74E-07	11.940%
15.00%	1.27E+02	1.04E-06	16.915%	1.81E-06	18.250%
20.00%	2.25E+02	1.99E-06	23.383%	3.44E-06	25.170%
25.00%	3.52E+02	3.35E-06	30.348%	6.08E-06	33.446%
30.00%	5.06E+02	5.36E-06	38.391%	9.80E-06	42.469%
35.00%	6.89E+02	8.32E-06	47.844%	1.63E-05	54.749%
40.00%	9.00E+02	1.31E-05	59.950%	2.79E-05	71.642%
45.00%	1.14E+03	2.10E-05	76.036%	5.36E-05	99.322%

Table J.8(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 1725 kN.

		P=1725 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	3.080025	4.389025	0.255025	2.49%	2.86%	0.66%
10.00%	56.25	12.496225	10.1124	2.1025	5.01%	4.34%	1.90%
15.00%	126.5625	28.5156	15.880225	6.125625	7.56%	5.44%	3.25%
20.00%	225	37.3321	23.474025	12.780625	8.65%	6.61%	4.70%
25.00%	351.5625	43.8244	33.5241	9.52576	9.38%	7.90%	4.05%
30.00%	506.25	50.055625	45.4276	38.6884	10.02%	9.20%	8.17%
35.00%	689.0625	57.3049	58.599025	56.4001	10.72%	10.45%	9.86%
40.00%	900	64.3204	71.5716	75.3424	11.36%	11.55%	11.40%
45.00%	1139.0625	69.3889	83.7225	95.4529	11.80%	12.49%	12.83%

Table J.8(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 2138 kN.

		P=2138 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	4.6225	6.1504	7.8961	2.29%	2.52%	2.75%
10.00%	56.25	18.1476	25.7049	33.64	4.53%	5.16%	5.69%
15.00%	126.5625	39.250225	59.059225	58.446025	6.66%	7.81%	7.50%
20.00%	225	67.650625	103.8361	82.6281	8.74%	10.36%	8.91%
25.00%	351.5625	103.32723	123.4321	108.7849	10.80%	11.30%	10.23%
30.00%	506.25	142.68303	144.4804	140.06723	12.70%	12.22%	11.60%
35.00%	689.0625	152.5225	164.22423	172.6596	13.13%	13.03%	12.88%
40.00%	900	153.76	181.57563	206.92823	13.18%	13.70%	14.10%
45.00%	1139.0625	229.37103	187.55303	232.2576	16.10%	13.93%	14.94%

Table J.8(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 2387 kN.

		P=2387 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	6.0025	8.7025	11.2225	2.24%	2.57%	2.80%
10.00%	56.25	22.09	35.4025	46.9225	4.30%	5.19%	5.73%
15.00%	126.5625	47.61	76.5625	106.09	6.31%	7.63%	8.62%
20.00%	225	82.0836	133.4025	176.89	8.28%	10.07%	11.13%
25.00%	351.5625	121.55063	198.81	213.16	10.08%	12.29%	12.22%
30.00%	506.25	165.6369	251.2225	254.4025	11.76%	13.82%	13.35%
35.00%	689.0625	199.79823	265.69	295.84	12.92%	14.21%	14.39%
40.00%	900	346.51823	270.6025	318.6225	17.02%	14.34%	14.94%
45.00%	1139.0625	548.73063	513.0225	462.25	21.41%	19.75%	17.99%

Table J.8(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'C' and lateral load 2671 kN.

		P=2671 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	6.25	11.9025	16.81	1.96%	2.56%	2.91%
10.00%	56.25	26.5225	46.24	65.61	4.04%	5.04%	5.75%
15.00%	126.5625	57.76	98.01	141.61	5.96%	7.33%	8.45%
20.00%	225	99.0025	166.41	243.36	7.80%	9.56%	11.07%
25.00%	351.5625	136.89	248.0625	374.4225	9.17%	11.67%	13.73%
30.00%	506.25	174.24	320.41	453.69	10.34%	13.26%	15.12%
35.00%	689.0625	406.0225	460.1025	473.0625	15.79%	15.89%	15.44%
40.00%	900	792.4225	894.01	812.25	22.06%	22.15%	20.23%
45.00%	1139.0625	1372.7025	1584.04	1672.81	29.04%	29.48%	29.03%

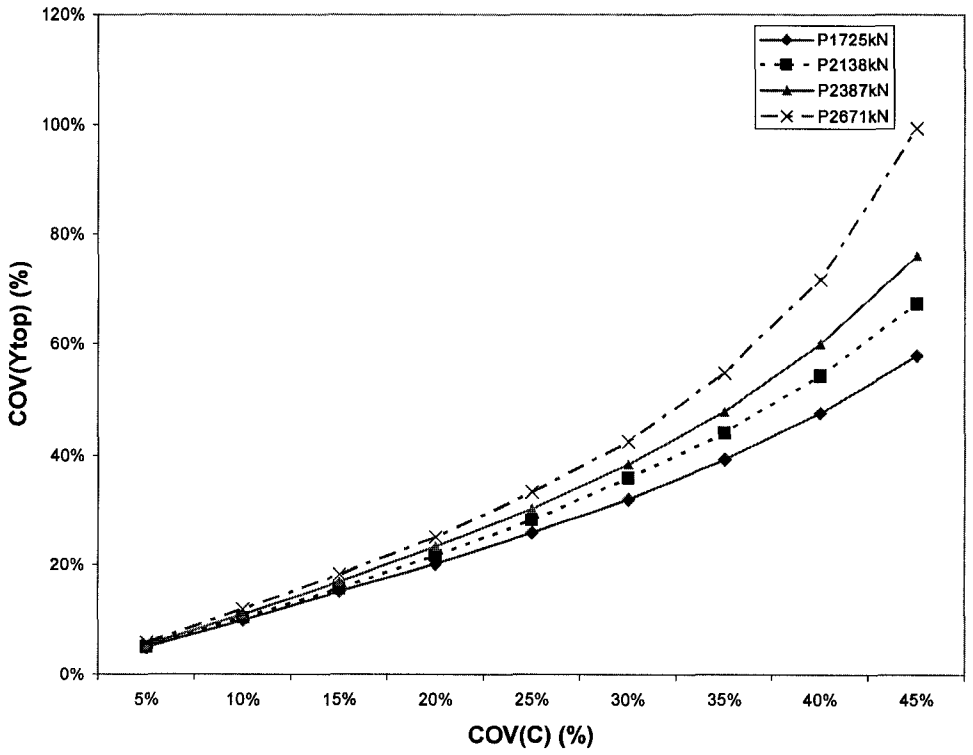

Fig. J.3 COV(Y_{Top}) for varying COV(C) in fixed head long (10T) pile group with spacing (4D).

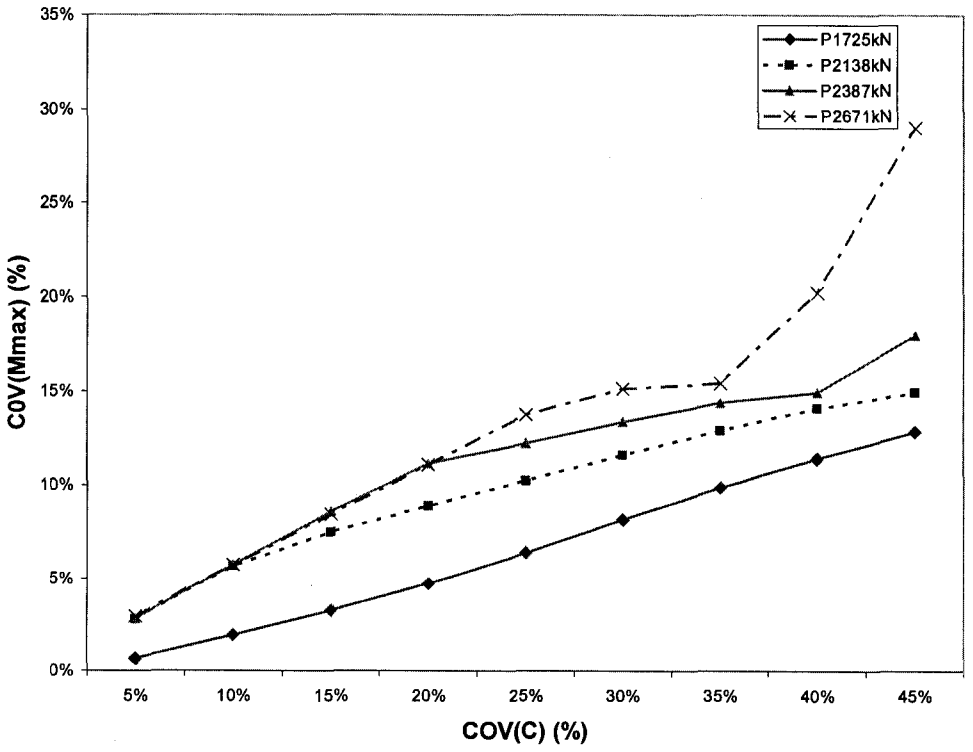

Fig. J.4(a) COV(M_{Max}) for varying COV(C) for pile C in fixed head long pile group with spacing (4D).

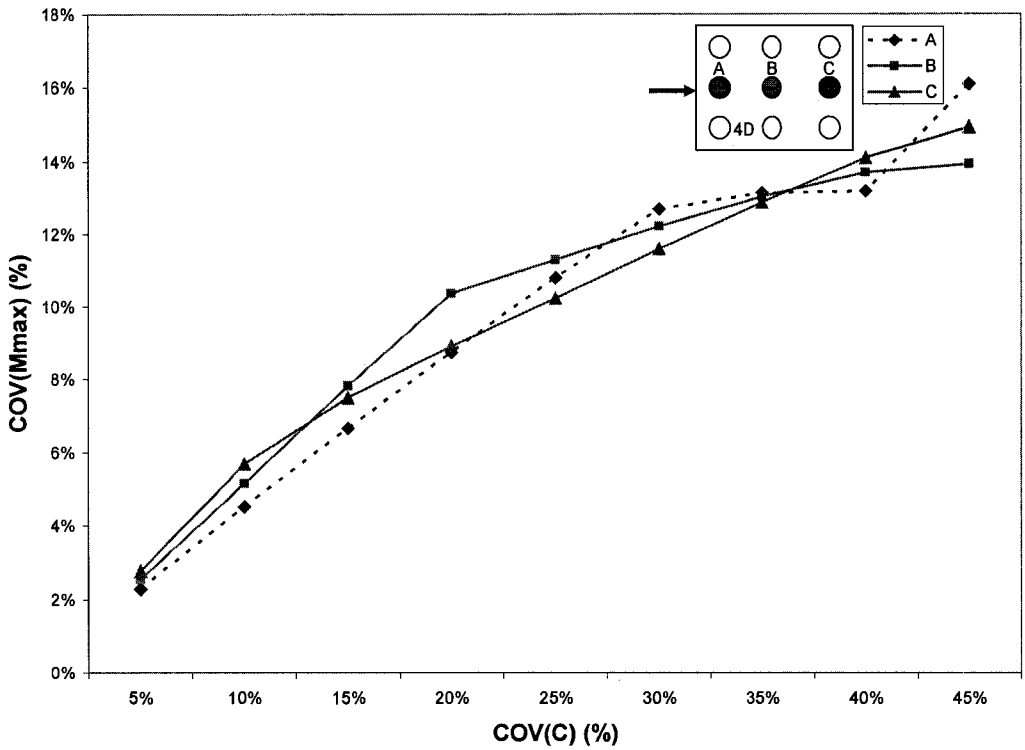

Fig. J.4(b) COV(M_{Max}) for varying COV(C) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (4D) at the optimum lateral load 2138 kN.

J.1.3 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (4D) with 'ε_{50}' as varying random design variable

Table J.9. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1725 kN and 2138 kN.

			P=1725 kN (180, 190, 210 kN)				P=2138 kN (220, 240, 260 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00273	69.18	75.24	80.91	0.00391	85.71	94.79	102.9
45%	9.9225E-06	0.00385	0.00282	68.62	74.7	80.41	0.00404	86.59	93.6	101.9
40%	0.00000784	0.0042	0.0029	67.86	74.28	79.99	0.00416	87.69	92.46	100.7
35%	6.0025E-06	0.00455	0.00298	67.11	73.71	79.67	0.00427	88.69	91.61	99.55
30%	0.00000441	0.0049	0.00307	66.39	73.11	79.27	0.00439	89.9	92.99	98.48
25%	3.0625E-06	0.00525	0.00315	66.77	72.51	78.79	0.0045	90.61	94.02	97.43
20%	0.00000196	0.0056	0.00324	67.73	71.85	78.22	0.0046	91.4	95.03	98.01
15%	1.1025E-06	0.00595	0.00332	68.54	71.26	77.7	0.00471	92.14	95.95	99.15
10%	0.00000049	0.0063	0.00339	69.29	71.6	77.18	0.00481	92.83	96.8	100.2
5%	1.225E-07	0.00665	0.00347	69.98	72.45	76.66	0.00491	93.47	97.6	101.2
0%	0	0.007	0.00354	70.61	73.25	76.14	0.005	94.08	98.34	102
5%	1.225E-07	0.00735	0.00361	71.2	73.98	76.3	0.00512	94.87	99.22	103
10%	0.00000049	0.0077	0.00368	71.76	74.66	77.12	0.00521	95.39	99.87	103.8
15%	1.1025E-06	0.00805	0.00374	72.29	75.3	77.89	0.0053	95.88	100.5	104.5
20%	0.00000196	0.0084	0.00381	72.79	75.91	78.61	0.00536	96.22	100.9	105.1
25%	3.0625E-06	0.00875	0.00388	73.27	76.48	79.27	0.00545	96.6	101.5	105.7
30%	0.00000441	0.0091	0.00394	73.73	77.03	79.9	0.00554	96.94	102.1	106.4
35%	6.0025E-06	0.00945	0.004	74.17	77.54	80.51	0.00562	97.24	102.6	107
40%	0.00000784	0.0098	0.00406	74.6	78.04	81.08	0.0057	97.52	103.1	107.6
45%	9.9225E-06	0.01015	0.00414	75.06	78.63	81.73	0.00578	97.78	103.5	108.1
50%	0.00001225	0.0105	0.00418	75.38	78.97	82.16	0.00586	98	103.9	108.7

Table J.10. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 2387 kN and 2671 kN.

			P=2387kN (240, 270, 290kN)				P=2671kN (270, 300, 320 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00483	102.3	105.6	115	0.00613	124.9	130.1	134.3
45%	9.9225E-06	0.00385	0.00497	103.4	107.1	113.4	0.00625	125	130.4	134.9
40%	0.00000784	0.0042	0.00509	104.2	108.1	112	0.00639	125.2	131	135.7
35%	6.0025E-06	0.00455	0.00521	104.8	109	112.5	0.00651	125.5	131.3	136.3
30%	0.00000441	0.0049	0.00535	105.7	110.2	113.9	0.00666	126	132	137.3
25%	3.0625E-06	0.00525	0.00547	106.4	111	115	0.00678	126.3	132.5	137.8
20%	0.00000196	0.0056	0.00558	107	111.8	116	0.0069	126.7	132.9	138.5
15%	1.1025E-06	0.00595	0.00569	107.6	112.6	116.9	0.00702	127	133.4	139
10%	0.00000049	0.0063	0.00582	108.4	113.5	117.9	0.00714	127.2	133.9	139.7
5%	1.225E-07	0.00665	0.00593	108.9	114.1	118.7	0.00727	127.5	134.7	140.4
0%	0	0.007	0.00603	109.4	114.7	119.5	0.00737	127.6	135	140.9
5%	1.225E-07	0.00735	0.00612	109.7	115.2	120	0.0075	127.8	135.5	141.6
10%	0.00000049	0.0077	0.00624	110.1	116	120.8	0.00762	127.9	135.8	142.2
15%	1.1025E-06	0.00805	0.00634	110.4	116.6	121.5	0.00773	128	136.1	142.8
20%	0.00000196	0.0084	0.00644	110.7	117.1	122.1	0.00784	128.1	136.4	143.3
25%	3.0625E-06	0.00875	0.00653	111	117.6	122.8	0.00795	128.2	136.7	143.8
30%	0.00000441	0.0091	0.00663	111.3	118	123.4	0.00806	128.2	136.9	144.2
35%	6.0025E-06	0.00945	0.00673	111.5	118.3	124	0.00817	128.3	137.1	144.6
40%	0.00000784	0.0098	0.00682	111.7	118.7	124.6	0.00828	128.3	137.3	145
45%	9.9225E-06	0.01015	0.00692	111.9	119	125.1	0.00839	128.3	137.5	145.3
50%	0.00001225	0.0105	0.00701	112	119.3	125.5	0.00852	128.4	137.8	145.7

Table J.11(a) Value of $COV(Y_{Top})$ for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1725 kN and 2138 kN.

		P=1725 kN		P=2138 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	4.90E-09	1.977%	1.10E-08	2.100%
10%	4.90E-07	2.10E-08	4.096%	4.00E-08	4.000%
15%	1.10E-06	4.41E-08	5.932%	8.70E-08	5.900%
20%	1.96E-06	8.12E-08	8.051%	1.44E-07	7.600%
25%	3.06E-06	1.33E-07	10.311%	2.26E-07	9.500%
30%	4.41E-06	1.89E-07	12.288%	3.31E-07	11.500%
35%	6.00E-06	2.60E-07	14.407%	4.56E-07	13.500%
40%	7.84E-06	3.36E-07	16.384%	5.93E-07	15.400%
45%	9.92E-06	4.36E-07	18.644%	7.57E-07	17.400%
50%	1.23E-05	5.26E-07	20.480%	9.51E-07	19.500%

Table J.11(b) Value of $COV(Y_{Top})$ for fixed head long pile (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 387 kN and 2671 kN.

		P=2387 kN		P=2671 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	9.025E-09	1.575%	1.32E-08	1.560%
10%	4.90E-07	4.41E-08	3.483%	5.76E-08	3.256%
15%	1.10E-06	1.056E-07	5.390%	1.26E-07	4.817%
20%	1.96E-06	1.849E-07	7.131%	2.21E-07	6.377%
25%	3.06E-06	2.809E-07	8.789%	3.42E-07	7.938%
30%	4.41E-06	4.096E-07	10.614%	4.90E-07	9.498%
35%	6.00E-06	5.776E-07	12.604%	6.89E-07	11.262%
40%	7.84E-06	7.482E-07	14.345%	8.93E-07	12.822%
45%	9.92E-06	9.506E-07	16.169%	1.14E-06	14.518%
50%	1.23E-05	1.188E-06	18.076%	1.43E-06	16.214%

Table J.12(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 1725 kN.

		P=1725 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.3721	0.585225	0.0324	0.86%	1.04%	0.24%
10%	4.90E-07	1.525225	2.3409	0.0009	1.75%	2.09%	0.04%
15%	1.10E-06	3.515625	4.0804	0.009025	2.66%	2.76%	0.12%
20%	1.96E-06	6.4009	4.1209	0.038025	3.58%	2.77%	0.26%
25%	3.06E-06	10.5625	3.940225	0.02304	4.60%	2.71%	0.20%
30%	4.41E-06	13.4689	3.8416	0.099225	5.20%	2.68%	0.41%
35%	6.00E-06	12.4609	3.667225	0.1764	5.00%	2.61%	0.55%
40%	7.84E-06	11.3569	3.5344	0.297025	4.77%	2.57%	0.72%
45%	9.92E-06	10.3684	3.861225	0.4356	4.56%	2.68%	0.87%
50%	1.23E-05	9.61	3.478225	0.390625	4.39%	2.55%	0.82%

Table J.12(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 2138 kN.

		P=2138 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.49	0.6561	0.81	0.74%	0.82%	0.88%
10%	4.90E-07	1.6384	2.356225	3.24	1.36%	1.56%	1.76%
15%	1.10E-06	3.4969	5.175625	7.155625	1.99%	2.31%	2.62%
20%	1.96E-06	5.8081	8.614225	12.567025	2.56%	2.98%	3.48%
25%	3.06E-06	8.970025	13.9876	17.098225	3.18%	3.80%	4.05%
30%	4.41E-06	12.3904	20.748025	15.6816	3.74%	4.63%	3.88%
35%	6.00E-06	18.275625	30.195025	13.875625	4.54%	5.59%	3.65%
40%	7.84E-06	24.157225	28.3024	11.9025	5.22%	5.41%	3.38%
45%	9.92E-06	31.304025	24.5025	9.61	5.95%	5.03%	3.04%
50%	1.23E-05	37.761025	20.748025	8.41	6.53%	4.63%	2.84%

Table J.12(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 2387 kN.

		P=2387 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.16	0.3025	0.4225	0.37%	0.48%	0.54%
10%	4.90E-07	0.7225	1.5625	2.1025	0.78%	1.09%	1.21%
15%	1.10E-06	1.96	4	5.29	1.28%	1.74%	1.92%
20%	1.96E-06	3.4225	7.0225	9.3025	1.69%	2.31%	2.55%
25%	3.06E-06	5.29	10.89	15.21	2.10%	2.88%	3.26%
30%	4.41E-06	7.84	15.21	22.5625	2.56%	3.40%	3.97%
35%	6.00E-06	11.2225	21.6225	33.0625	3.06%	4.05%	4.81%
40%	7.84E-06	14.0625	28.09	39.69	3.43%	4.62%	5.27%
45%	9.92E-06	18.0625	35.4025	34.2225	3.88%	5.19%	4.90%
50%	1.23E-05	23.5225	46.9225	27.5625	4.43%	5.97%	4.39%

Table J.12(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and lateral load 2671 kN.

		P=2671 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.0225	0.16	0.36	0.12%	0.30%	0.43%
10%	4.90E-07	0.1225	0.9025	1.5625	0.27%	0.70%	0.89%
15%	1.10E-06	0.25	1.8225	3.61	0.39%	1.00%	1.35%
20%	1.96E-06	0.49	3.0625	5.76	0.55%	1.30%	1.70%
25%	3.06E-06	0.9025	4.41	9	0.74%	1.56%	2.13%
30%	4.41E-06	1.21	6.0025	11.9025	0.86%	1.81%	2.45%
35%	6.00E-06	1.96	8.41	17.2225	1.10%	2.15%	2.95%
40%	7.84E-06	2.4025	9.9225	21.6225	1.21%	2.33%	3.30%
45%	9.92E-06	2.7225	12.6025	27.04	1.29%	2.63%	3.69%
50%	1.23E-05	3.0625	14.8225	32.49	1.37%	2.85%	4.05%

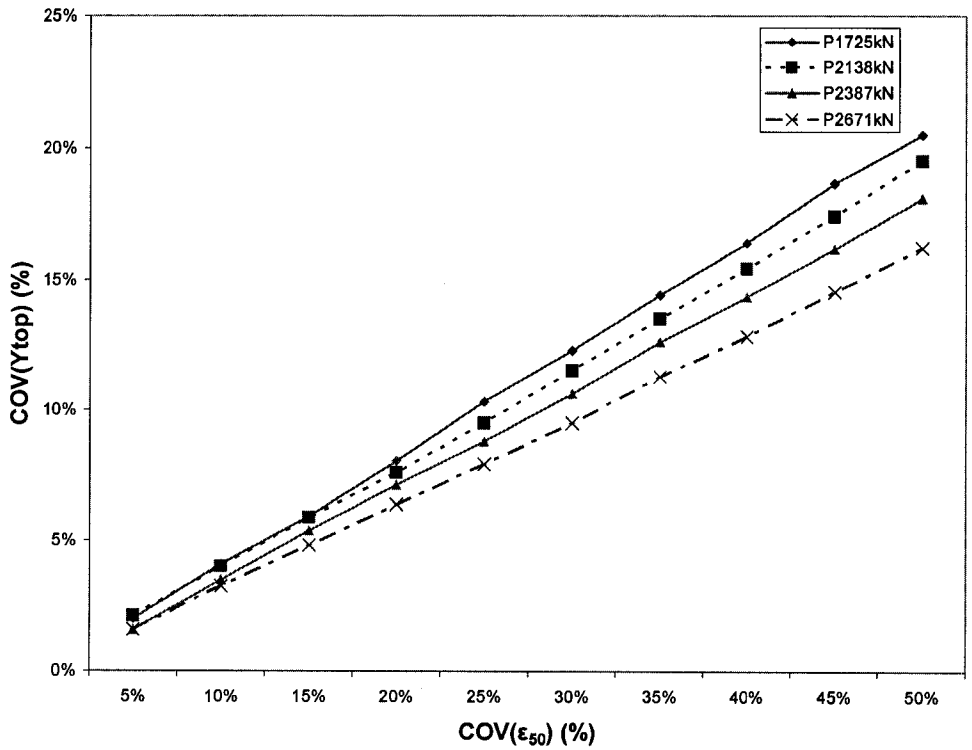

Fig. J.5 COV(Y_{Top}) for varying COV(ε_{50}) in fixed head long (10T) pile group with spacing (4D).

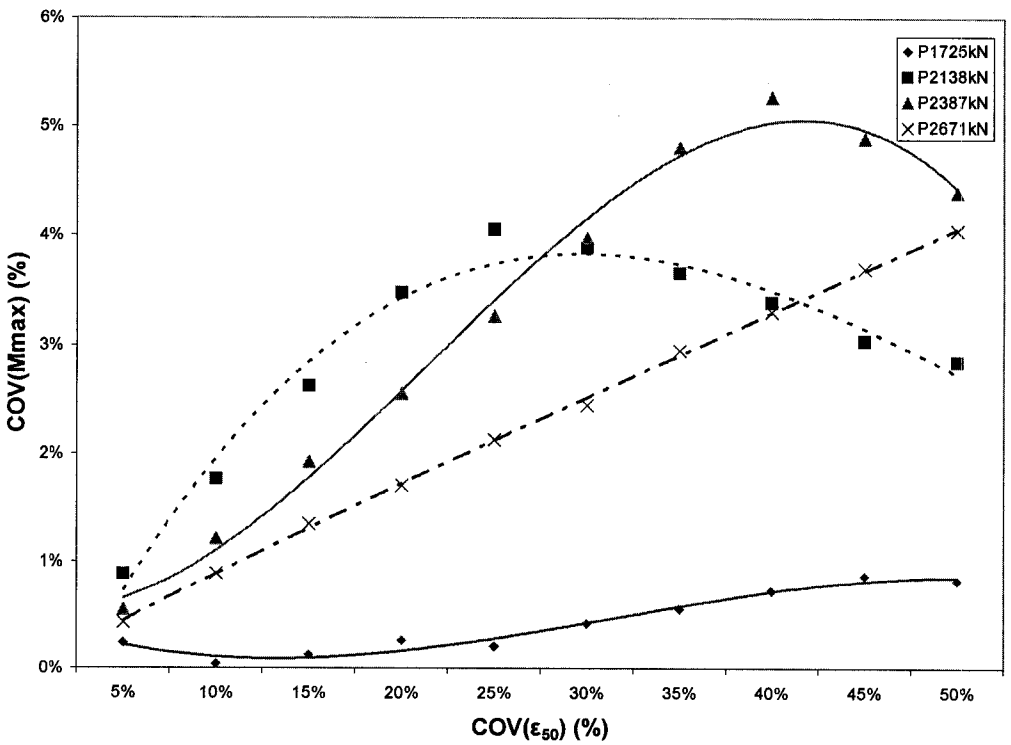

Fig. J.6(a) COV(M_{Max}) for varying COV(ε_{50}) for pile C in fixed head long pile group with spacing (4D).

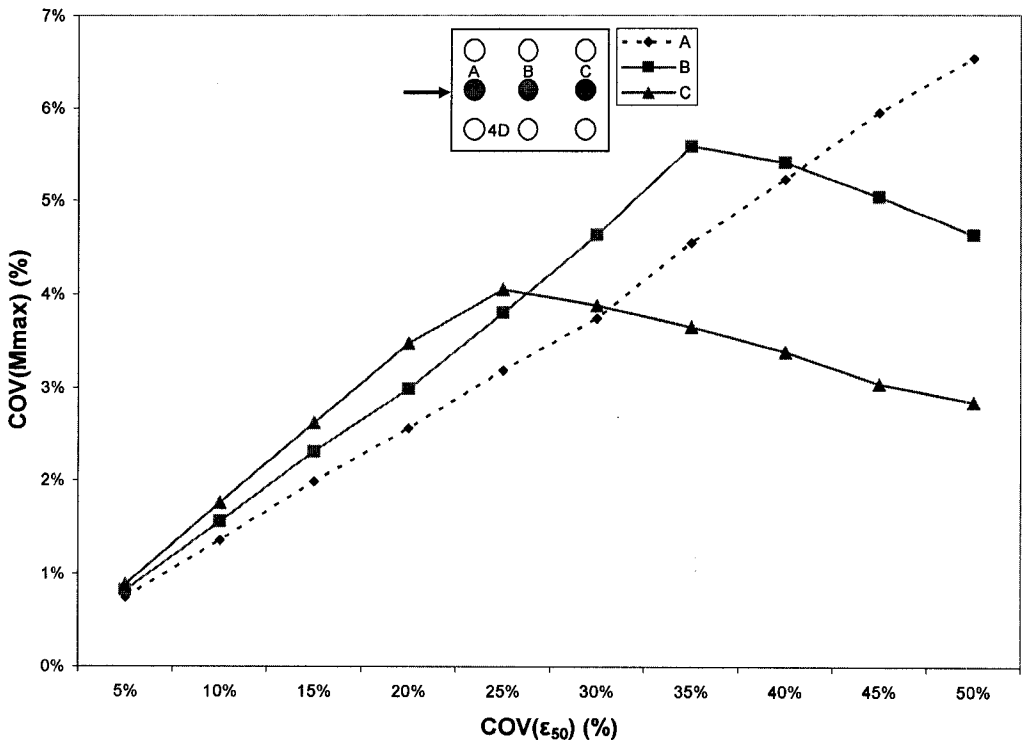

Fig. J.6(b) COV(M_{Max}) for varying COV(ε_{50}) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (4D) at the optimum lateral load 2138 kN.

J.1.4 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (4D) and with 'EI' as varying random design variable

Table J.13. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1725 kN and 2138 kN.

			P=1725 kN (180, 190, 210 kN)				P=2138 kN (220, 240, 260 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00505	65.22	71.49	77.1	0.00728	81.55	89.4	97.24
45%	2.45E+09	60500	0.0048	64.89	71.29	77.04	0.00689	83.18	88.77	96.64
40%	1.94E+09	66000	0.00458	64.59	71.09	76.97	0.00656	84.68	88.14	96.1
35%	1.48E+09	71500	0.00439	64.29	70.9	76.89	0.00627	86.09	89.23	95.61
30%	1.09E+09	77000	0.00422	64.31	70.71	76.8	0.00602	87.43	90.75	95.14
25%	7.56E+08	82500	0.00407	65.48	70.51	76.7	0.00581	88.76	92.26	95.1
20%	4.84E+08	88000	0.00395	66.71	70.29	76.56	0.00562	89.96	93.64	96.68
15%	2.72E+08	93500	0.00383	67.76	70.09	76.46	0.00544	91.04	94.89	98.11
10%	1.21E+08	99000	0.00372	68.77	71.13	76.36	0.00528	92.11	96.11	99.5
5%	3.03E+07	104500	0.00363	69.71	72.21	76.26	0.00513	93.12	97.25	100.8
0%	0.00E+00	110000	0.00354	70.61	73.25	76.14	0.005	94.08	98.34	102
5%	3.03E+07	115500	0.00346	71.46	74.23	76.54	0.00489	95.12	99.47	103.3
10%	1.21E+08	121000	0.00338	72.28	75.17	77.6	0.00478	95.98	100.4	104.4
15%	2.72E+08	126500	0.00331	73.07	76.06	78.61	0.00467	96.83	101.4	105.5
20%	4.84E+08	132000	0.00324	73.82	76.91	79.59	0.00458	97.65	102.3	106.5
25%	7.56E+08	137500	0.00318	74.55	77.74	80.52	0.00449	98.41	103.3	107.5
30%	1.09E+09	143000	0.00313	75.26	78.53	81.42	0.00439	99.12	104	108.4
35%	1.48E+09	148500	0.00307	75.94	79.3	82.29	0.00431	99.81	104.8	109.3
40%	1.94E+09	154000	0.00302	76.6	80.04	83.12	0.00424	100.5	105.7	110.3
45%	2.45E+09	159500	0.00298	77.24	80.76	83.92	0.00417	101.1	106.5	111.1
50%	3.03E+09	165000	0.00293	77.86	81.45	84.7	0.0041	101.7	107.3	112

Table J.14. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 2387 kN and 2671 kN.

			P=2387 kN (240, 270, 290 kN)				P=2671 kN (270, 300, 320 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00899	97.72	101.4	108.4	0.0114	119	124.3	128.6
45%	2.45E+09	60500	0.00847	99.09	103	107.6	0.0107	119.8	125.3	129.8
40%	1.94E+09	66000	0.00803	100.4	104.5	107.8	0.0101	120.8	126.5	131.2
35%	1.48E+09	71500	0.00766	101.7	106	109.5	0.00957	121.7	127.6	132.4
30%	1.09E+09	77000	0.00735	103	107.5	111.2	0.00913	122.7	128.7	133.7
25%	7.56E+08	82500	0.00706	104.1	108.8	112.7	0.00874	123.6	129.7	134.9
20%	4.84E+08	88000	0.0068	105.2	110.1	114.2	0.0084	124.6	130.8	136.2
15%	2.72E+08	93500	0.00658	106.3	111.3	115.5	0.00813	125.5	132.1	137.6
10%	1.21E+08	99000	0.00639	107.6	112.7	117.1	0.00785	126.3	133.1	138.8
5%	3.03E+07	104500	0.0062	108.5	113.7	118.3	0.00761	127	134.2	139.9
0%	0.00E+00	110000	0.00603	109.4	114.7	119.5	0.00737	127.6	135	140.9
5%	3.03E+07	115500	0.00586	110.1	115.6	120.4	0.00719	128.4	136	142.1
10%	1.21E+08	121000	0.00572	110.9	116.6	121.5	0.007	129	136.9	143.2
15%	2.72E+08	126500	0.00559	111.7	117.6	122.6	0.00684	129.6	137.7	144.3
20%	4.84E+08	132000	0.00548	112.5	118.7	123.8	0.00668	130.3	138.5	145.4
25%	7.56E+08	137500	0.00537	113.2	119.6	124.8	0.00654	130.9	139.3	146.4
30%	1.09E+09	143000	0.00526	113.9	120.5	125.8	0.0064	131.4	140	147.3
35%	1.48E+09	148500	0.00516	114.5	121.2	126.7	0.00628	132	140.7	148.2
40%	1.94E+09	154000	0.00507	115.1	122	127.7	0.00616	132.5	141.4	149.1
45%	2.45E+09	159500	0.00499	115.7	122.8	128.6	0.00605	133	142.1	149.9
50%	3.03E+09	165000	0.00491	116.3	123.5	129.6	0.00595	133.6	142.8	150.8

Table J.15(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1725 kN and 2138 kN.

		P=1725 kN		P=2138 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	7.23E-09	2.401%	1.44E-08	2.400%
10%	1.21E+08	2.89E-08	4.802%	6.25E-08	5.000%
15%	2.72E+08	6.76E-08	7.345%	1.48E-07	7.700%
20%	4.84E+08	1.26E-07	10.028%	2.70E-07	10.400%
25%	7.56E+08	1.98E-07	12.571%	4.36E-07	13.200%
30%	1.09E+09	2.97E-07	15.395%	6.64E-07	16.300%
35%	1.48E+09	4.36E-07	18.644%	9.60E-07	19.600%
40%	1.94E+09	6.08E-07	22.034%	1.35E-06	23.200%
45%	2.45E+09	8.28E-07	25.706%	1.85E-06	27.200%
50%	3.03E+09	1.12E-06	29.944%	2.53E-06	31.800%

Table J.15(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 2387 kN and 2671 kN.

		P=2387 kN		P=2671 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	2.89E-08	2.819%	4.41E-08	2.849%
10%	1.21E+08	1.12E-07	5.556%	1.81E-07	5.767%
15%	2.72E+08	2.45E-07	8.209%	4.16E-07	8.752%
20%	4.84E+08	4.36E-07	10.945%	7.40E-07	11.669%
25%	7.56E+08	7.14E-07	14.013%	1.21E-06	14.925%
30%	1.09E+09	1.09E-06	17.330%	1.86E-06	18.521%
35%	1.48E+09	1.56E-06	20.730%	2.71E-06	22.320%
40%	1.94E+09	2.19E-06	24.544%	3.88E-06	26.730%
45%	2.45E+09	3.03E-06	28.856%	5.41E-06	31.547%
50%	3.03E+09	4.16E-06	33.831%	7.43E-06	36.974%

Table J.16(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 1725 kN.

		P=1725 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.765625	1.0201	0.0196	1.24%	1.38%	0.18%
10%	1.21E+08	3.080025	4.0804	0.3844	2.49%	2.76%	0.81%
15%	2.72E+08	7.049025	8.910225	1.155625	3.76%	4.08%	1.41%
20%	4.84E+08	12.638025	10.9561	2.295225	5.03%	4.52%	1.99%
25%	7.56E+08	20.566225	13.068225	1.45924	6.42%	4.94%	1.59%
30%	1.09E+09	29.975625	15.2881	5.3361	7.75%	5.34%	3.03%
35%	1.48E+09	33.930625	17.64	7.29	8.25%	5.73%	3.55%
40%	1.94E+09	36.060025	20.025625	9.455625	8.50%	6.11%	4.04%
45%	2.45E+09	38.130625	22.420225	11.8336	8.75%	6.46%	4.52%
50%	3.03E+09	39.9424	24.8004	14.44	8.95%	6.80%	4.99%

Table J.16(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 2138 kN.

		P=2138 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	1	1.2321	1.5625	1.06%	1.13%	1.23%
10%	1.21E+08	3.744225	4.601025	6.0025	2.06%	2.18%	2.40%
15%	2.72E+08	8.381025	10.595025	13.653025	3.08%	3.31%	3.62%
20%	4.84E+08	14.784025	18.7489	24.1081	4.09%	4.40%	4.81%
25%	7.56E+08	23.280625	30.4704	38.44	5.13%	5.61%	6.08%
30%	1.09E+09	34.164025	43.890625	43.9569	6.21%	6.74%	6.50%
35%	1.48E+09	47.0596	60.606225	46.854025	7.29%	7.92%	6.71%
40%	1.94E+09	62.5681	77.0884	50.41	8.41%	8.93%	6.96%
45%	2.45E+09	80.2816	78.588225	52.2729	9.52%	9.01%	7.09%
50%	3.03E+09	101.50563	80.1025	54.4644	10.71%	9.10%	7.24%

Table J.16(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 2387 kN.

		P=2387 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.64	0.9025	1.1025	0.73%	0.83%	0.88%
10%	1.21E+08	2.7225	3.8025	4.84	1.51%	1.70%	1.84%
15%	2.72E+08	7.29	9.9225	12.6025	2.47%	2.75%	2.97%
20%	4.84E+08	13.3225	18.49	23.04	3.34%	3.75%	4.02%
25%	7.56E+08	20.7025	29.16	36.6025	4.16%	4.71%	5.06%
30%	1.09E+09	29.7025	42.25	53.29	4.98%	5.67%	6.11%
35%	1.48E+09	40.96	57.76	73.96	5.85%	6.63%	7.20%
40%	1.94E+09	54.0225	76.5625	99.0025	6.72%	7.63%	8.33%
45%	2.45E+09	68.973025	98.01	110.25	7.59%	8.63%	8.79%
50%	3.03E+09	86.3041	122.1025	112.36	8.49%	9.63%	8.87%

Table J.16(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'EI' and lateral load 2671 kN.

		P=2671 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.49	0.81	1.21	0.55%	0.67%	0.78%
10%	1.21E+08	1.8225	3.61	4.84	1.06%	1.41%	1.56%
15%	2.72E+08	4.2025	7.84	11.2225	1.61%	2.07%	2.38%
20%	4.84E+08	8.1225	14.8225	21.16	2.23%	2.85%	3.26%
25%	7.56E+08	13.3225	23.04	33.0625	2.86%	3.56%	4.08%
30%	1.09E+09	18.9225	31.9225	46.24	3.41%	4.19%	4.83%
35%	1.48E+09	26.5225	42.9025	62.41	4.04%	4.85%	5.61%
40%	1.94E+09	34.2225	55.5025	80.1025	4.58%	5.52%	6.35%
45%	2.45E+09	43.56	70.56	101.0025	5.17%	6.22%	7.13%
50%	3.03E+09	53.29	85.5625	123.21	5.72%	6.85%	7.88%

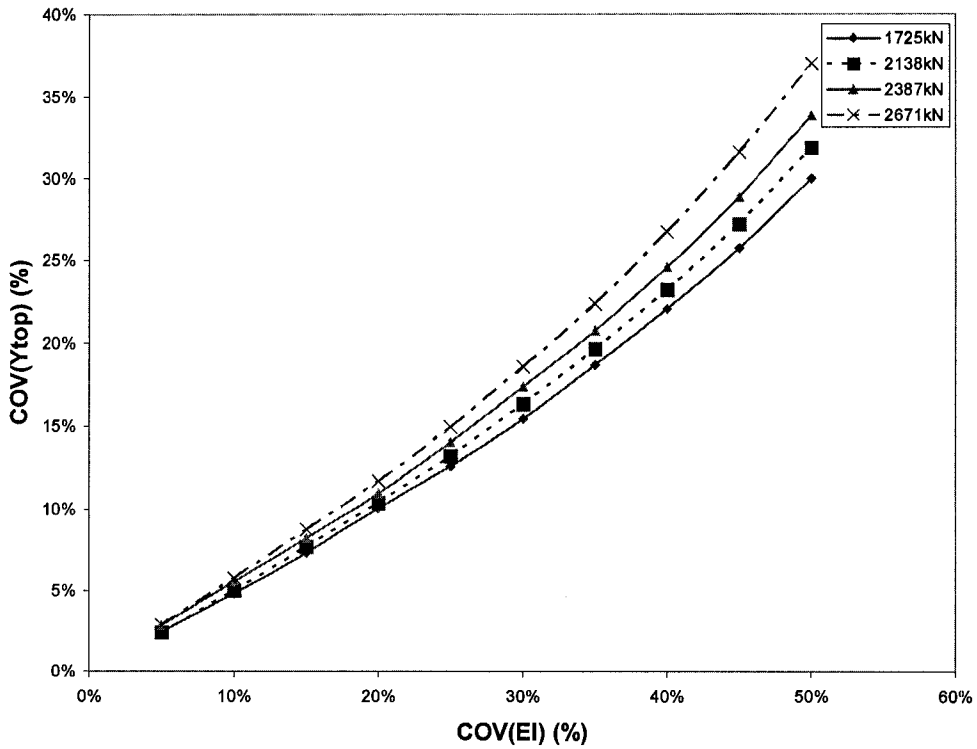

Fig. J.7 COV(Y_{Top}) for varying COV(EI) in fixed head long (10T) pile group with spacing (4D).

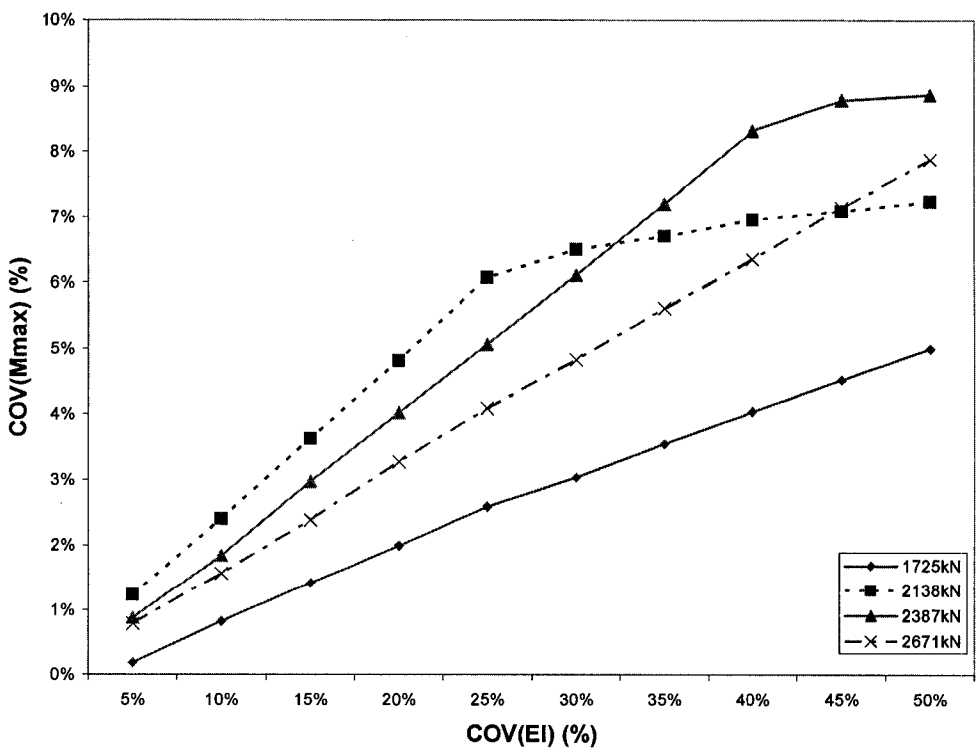

Fig. J.8(a) COV(M_{Max}) for varying COV(EI) for pile C in fixed head long pile group with spacing (4D).

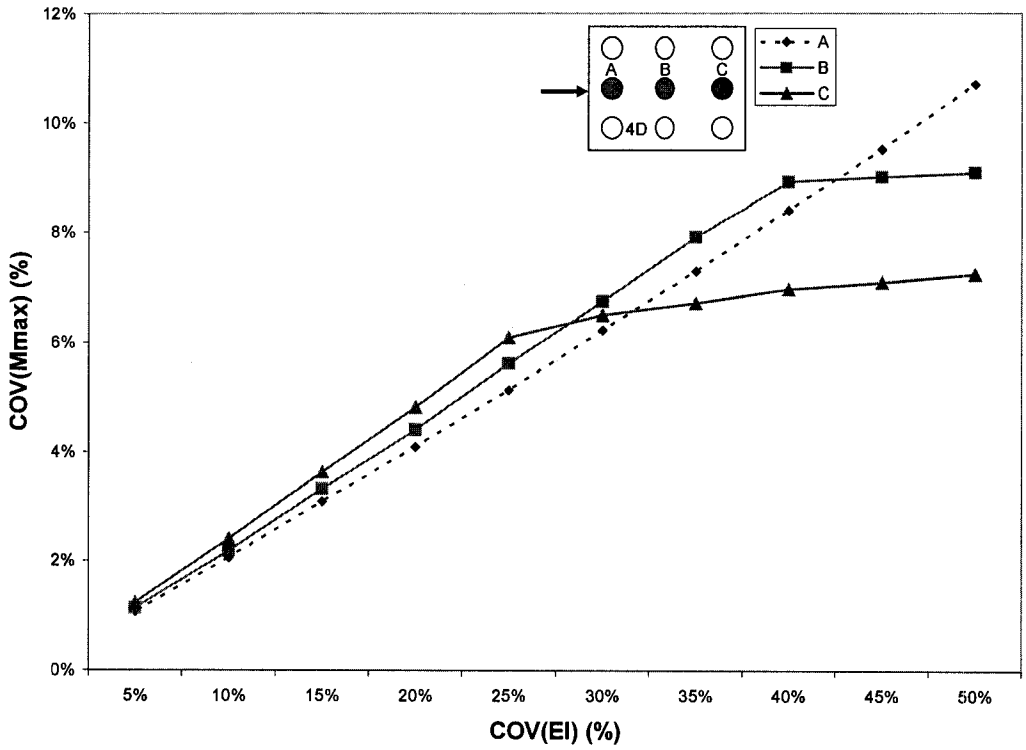

Fig. J.8(b) COV(M_{Max}) for varying COV(EI) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (4D) at the optimum lateral load 2138 kN.

J.1.5 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (4D) and with 'k' as varying random design variable

Table J.17. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1725 kN and 2138 kN.

			P=1725 kN (180, 190, 210 kN)				P=2138 kN (220, 240, 260 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00355	70.56	72.57	75.34	0.005	93.81	98.27	102.1
45%	3.75E+09	74800	0.00354	70.52	73.19	75.67	0.005	93.91	98.34	102.1
40%	2.96E+09	81600	0.00354	70.56	73.22	75.81	0.005	93.97	98.34	102.1
35%	2.27E+09	88400	0.00354	70.59	73.26	75.89	0.005	93.99	98.37	102.1
30%	1.66E+09	95200	0.00354	70.6	73.26	75.96	0.005	94	98.4	102.1
25%	1.16E+09	102000	0.00354	70.61	73.26	75.99	0.005	94.02	98.38	102.1
20%	7.40E+08	108800	0.00354	70.61	73.26	76.03	0.005	94.03	98.37	102.1
15%	4.16E+08	115600	0.00354	70.61	73.25	76.06	0.005	94.04	98.37	102.1
10%	1.85E+08	122400	0.00354	70.61	73.25	76.09	0.005	94.06	98.36	102.1
5%	4.62E+07	129200	0.00354	70.61	73.25	76.11	0.005	94.07	98.35	102.1
0%	0.00E+00	136000	0.00354	70.61	73.25	76.14	0.005	94.08	98.34	102
5%	4.62E+07	142800	0.00354	70.6	73.24	76.16	0.005	94.09	98.34	102
10%	1.85E+08	149600	0.00354	70.59	73.23	76.17	0.005	94.1	98.33	102
15%	4.16E+08	156400	0.00354	70.59	73.22	76.17	0.005	94.11	98.33	102
20%	7.40E+08	163200	0.00354	70.58	73.21	76.18	0.005	94.12	98.32	102
25%	1.16E+09	170000	0.00353	70.53	73.16	76.23	0.005	94.14	98.32	102
30%	1.66E+09	176800	0.00353	70.52	73.15	76.23	0.005	94.15	98.31	102
35%	2.27E+09	183600	0.00353	70.52	73.14	76.24	0.005	94.16	98.31	102
40%	2.96E+09	190400	0.00353	70.51	73.14	76.24	0.005	94.17	98.31	101.9
45%	3.75E+09	197200	0.00353	70.51	73.14	76.24	0.005	94.18	98.3	101.9
50%	4.62E+09	204000	0.00353	70.51	73.14	76.24	0.005	94.19	98.3	101.9

Table J.18. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 2387 kN and 2671 kN.

			P=238 7kN (240, 270, 290 kN)				P=2671 kN (270, 300, 320 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00604	108.9	114.6	119.6	0.0074	127.4	134.7	140.9
45%	3.75E+09	74800	0.00604	109	114.7	119.6	0.0074	127.5	134.7	140.9
40%	2.96E+09	81600	0.00604	109.1	114.7	119.6	0.0074	127.7	134.8	140.9
35%	2.27E+09	88400	0.00604	109.1	114.7	119.6	0.00737	127.7	134.8	140.9
30%	1.66E+09	95200	0.00604	109.2	114.7	119.6	0.00737	127.7	134.9	140.9
25%	1.16E+09	102000	0.00604	109.2	114.7	119.5	0.00737	127.7	134.9	140.9
20%	7.40E+08	108800	0.00604	109.3	114.7	119.5	0.00737	127.7	135	140.9
15%	4.16E+08	115600	0.00604	109.3	114.7	119.5	0.00737	127.7	135	140.9
10%	1.85E+08	122400	0.00604	109.4	114.7	119.5	0.00737	127.7	135	140.9
5%	4.62E+07	129200	0.00604	109.4	114.7	119.5	0.00737	127.7	135	140.9
0%	0.00E+00	136000	0.00603	109.4	114.7	119.5	0.00737	127.6	135	140.9
5%	4.62E+07	142800	0.00603	109.4	114.8	119.4	0.00737	127.6	135	140.9
10%	1.85E+08	149600	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141
15%	4.16E+08	156400	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141
20%	7.40E+08	163200	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141
25%	1.16E+09	170000	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141.1
30%	1.66E+09	176800	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141.1
35%	2.27E+09	183600	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141.1
40%	2.96E+09	190400	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141.1
45%	3.75E+09	197200	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141.1
50%	4.62E+09	204000	0.00602	109.3	114.6	119.2	0.00737	127.6	135.1	141.1

Table J.19(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1477 kN and 1832 kN.

		P=1725 kN		P=2138 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	0.00E+00	0.000%
20%	7.40E+08	0.00E+00	0.000%	0.00E+00	0.000%
25%	1.16E+09	2.50E-11	0.141%	0.00E+00	0.000%
30%	1.66E+09	2.50E-11	0.141%	0.00E+00	0.000%
35%	2.27E+09	2.50E-11	0.141%	0.00E+00	0.000%
40%	2.96E+09	2.50E-11	0.141%	0.00E+00	0.000%
45%	3.75E+09	2.50E-11	0.141%	0.00E+00	0.000%
50%	4.62E+09	1.00E-10	0.282%	0.00E+00	0.000%

Table J.19(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (4D) and with varying 'k' and lateral load 2387 kN and 2671 kN.

		P=2387 kN		P=2671 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	2.50E-11	0.083%	0.00E+00	0.000%
10%	1.85E+08	1.00E-10	0.166%	0.00E+00	0.000%
15%	4.16E+08	1.00E-10	0.166%	0.00E+00	0.000%
20%	7.40E+08	1.00E-10	0.166%	0.00E+00	0.000%
25%	1.16E+09	1.00E-10	0.166%	0.00E+00	0.000%
30%	1.66E+09	1.00E-10	0.166%	0.00E+00	0.000%
35%	2.27E+09	1.00E-10	0.166%	0.00E+00	0.000%
40%	2.96E+09	1.00E-10	0.166%	2.25E-10	0.204%
45%	3.75E+09	1.00E-10	0.166%	2.25E-10	0.204%
50%	4.62E+09	1.00E-10	0.166%	2.25E-10	0.204%

Table J.20(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 1725 kN.

		P=1725 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	2.5E-05	2.5E-05	0.000625	0.01%	0.01%	0.03%
10%	1.85E+08	1E-04	1E-04	0.0016	0.01%	0.01%	0.05%
15%	4.16E+08	1E-04	0.000225	0.003025	0.01%	0.02%	0.07%
20%	7.40E+08	0.000225	0.000625	0.005625	0.02%	0.03%	0.10%
25%	1.16E+09	0.0016	0.0025	0.00576	0.06%	0.07%	0.10%
30%	1.66E+09	0.0016	0.003025	0.018225	0.06%	0.08%	0.18%
35%	2.27E+09	0.001225	0.0036	0.030625	0.05%	0.08%	0.23%
40%	2.96E+09	0.000625	0.0016	0.046225	0.04%	0.05%	0.28%
45%	3.75E+09	2.5E-05	0.000625	0.081225	0.01%	0.03%	0.37%
50%	4.62E+09	0.000625	0.081225	0.2025	0.04%	0.39%	0.59%

Table J.20(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 2138 kN.

		P=2138 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.0001	2.5E-05	0.0025	0.01%	0.01%	0.05%
10%	1.85E+08	0.0004	0.000225	0.0025	0.02%	0.02%	0.05%
15%	4.16E+08	0.001225	0.0004	0.0025	0.04%	0.02%	0.05%
20%	7.40E+08	0.002025	0.000625	0.0025	0.05%	0.03%	0.05%
25%	1.16E+09	0.0036	0.0009	0.0025	0.06%	0.03%	0.05%
30%	1.66E+09	0.005625	0.002025	0.0025	0.08%	0.05%	0.05%
35%	2.27E+09	0.007225	0.0009	0.0025	0.09%	0.03%	0.05%
40%	2.96E+09	0.01	0.000225	0.01	0.11%	0.02%	0.10%
45%	3.75E+09	0.018225	0.0004	0.01	0.14%	0.02%	0.10%
50%	4.62E+09	0.0361	0.000225	0.01	0.20%	0.02%	0.10%

Table J.20(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 2387 kN.

		P=2387 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0	0.0025	0.0025	0.00%	0.04%	0.04%
10%	1.85E+08	0.0025	0.0025	0.0225	0.05%	0.04%	0.13%
15%	4.16E+08	0	0.0025	0.0225	0.00%	0.04%	0.13%
20%	7.40E+08	0	0.0025	0.0225	0.00%	0.04%	0.13%
25%	1.16E+09	0.0025	0.0025	0.0225	0.05%	0.04%	0.13%
30%	1.66E+09	0.0025	0.0025	0.04	0.05%	0.04%	0.17%
35%	2.27E+09	0.01	0.0025	0.04	0.09%	0.04%	0.17%
40%	2.96E+09	0.01	0.0025	0.04	0.09%	0.04%	0.17%
45%	3.75E+09	0.0225	0.0025	0.04	0.14%	0.04%	0.17%
50%	4.62E+09	0.04	0	0.04	0.18%	0.00%	0.17%

Table J.20(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'k' and lateral load 2671 kN.

		P=2671 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.0025	0	0	0.04%	0.00%	0.00%
10%	1.85E+08	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
15%	4.16E+08	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
20%	7.40E+08	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
25%	1.16E+09	0.0025	0.01	0.01	0.04%	0.07%	0.07%
30%	1.66E+09	0.0025	0.01	0.01	0.04%	0.07%	0.07%
35%	2.27E+09	0.0025	0.0225	0.01	0.04%	0.11%	0.07%
40%	2.96E+09	0.0025	0.0225	0.01	0.04%	0.11%	0.07%
45%	3.75E+09	0.0025	0.04	0.01	0.04%	0.15%	0.07%
50%	4.62E+09	0.01	0.04	0.01	0.08%	0.15%	0.07%

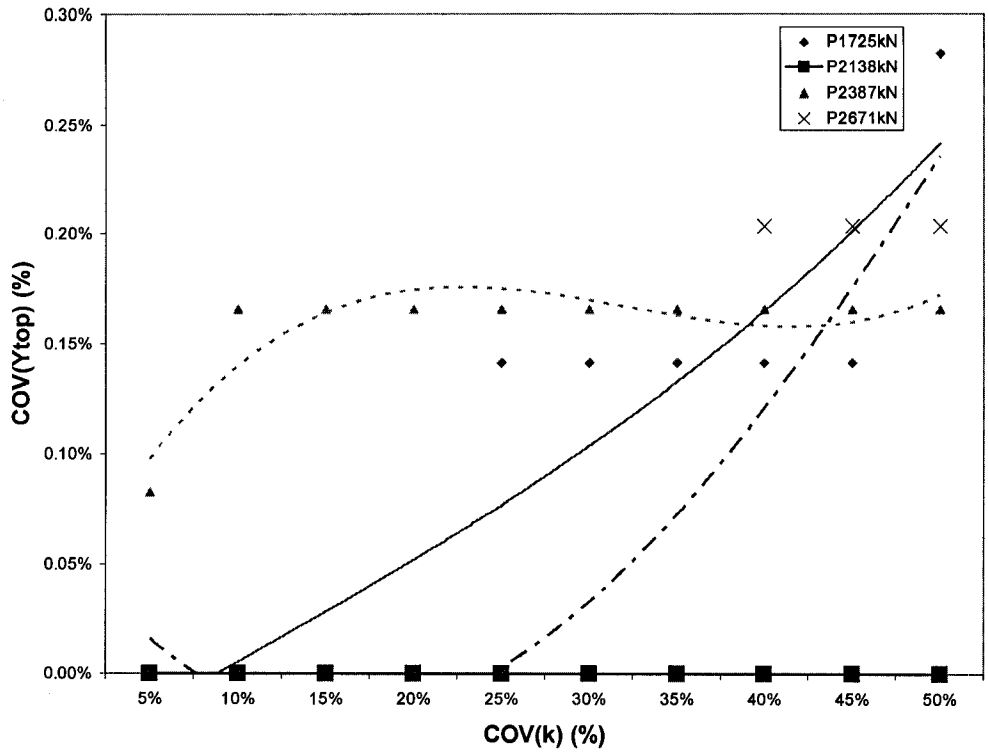

Fig. J.9 COV(Y_{Top}) for varying COV(k) in fixed head long (10T) pile group with spacing (4D).

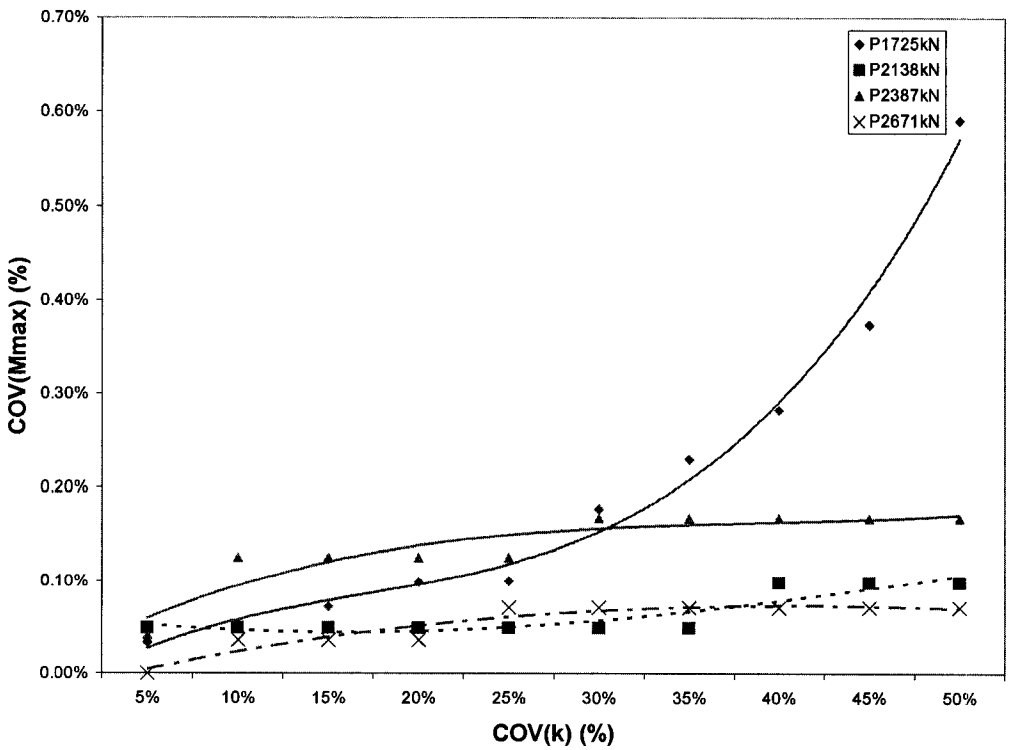

Fig. J.10(a) COV(M_{Max}) for varying COV(k) for pile C in fixed head long pile group with spacing (4D).

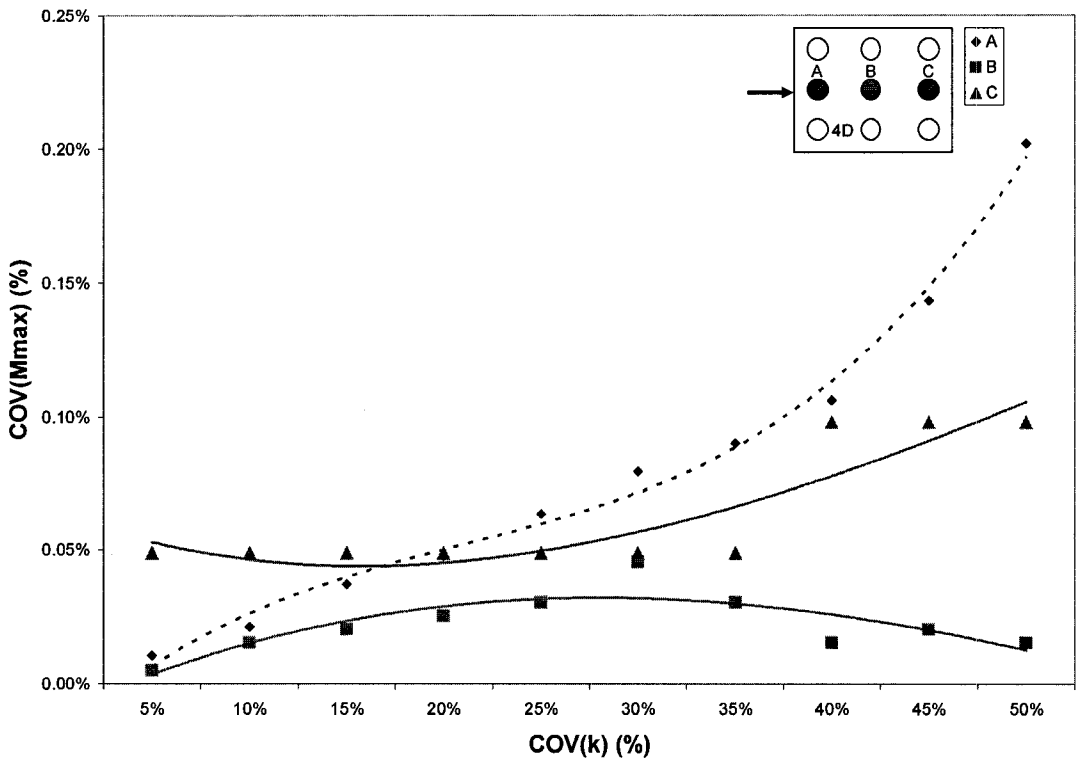

Fig. J.10(b) COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (4D) at the optimum lateral load 2138 kN.

J.1.6 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (4D) and with 'γ'' as varying random design variable

Table J.21. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 1725 kN and 2138 kN.

			P=1725 kN (180, 190, 210 kN)				P=2138 kN (220, 240, 260 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00355	70.79	73.45	76.22	0.00502	94.31	98.59	102.3
45%	7.049025	3.245	0.00355	70.77	73.43	76.2	0.00501	94.28	98.56	102.3
40%	5.5696	3.54	0.00355	70.75	73.41	76.2	0.00501	94.26	98.54	102.3
35%	4.264225	3.835	0.00355	70.74	73.39	76.2	0.00501	94.24	98.52	102.2
30%	3.1329	4.13	0.00354	70.72	73.37	76.19	0.00501	94.22	98.49	102.2
25%	2.175625	4.425	0.00354	70.7	73.35	76.18	0.00501	94.19	98.47	102.2
20%	1.3924	4.72	0.00354	70.68	73.33	76.17	0.00501	94.17	98.44	102.2
15%	0.783225	5.015	0.00354	70.66	73.31	76.16	0.00501	94.15	98.42	102.1
10%	0.3481	5.31	0.00354	70.64	73.29	76.15	0.005	94.13	98.39	102.1
5%	0.087025	5.605	0.00354	70.63	73.27	76.15	0.005	94.1	98.37	102.1
0%	0	5.9	0.00354	70.61	73.25	76.14	0.005	94.08	98.34	102
5%	0.087025	6.195	0.00354	70.59	73.23	76.13	0.005	94.06	98.32	102
10%	0.3481	6.49	0.00354	70.57	73.2	76.12	0.005	94.04	98.3	102
15%	0.783225	6.785	0.00354	70.55	73.18	76.11	0.005	94.01	98.27	102
20%	1.3924	7.08	0.00353	70.53	73.16	76.1	0.005	93.99	98.25	101.9
25%	2.175625	7.375	0.00353	70.51	73.14	76.1	0.00499	93.97	98.22	101.9
30%	3.1329	7.67	0.00353	70.5	73.12	76.09	0.00499	93.95	98.2	101.9
35%	4.264225	7.965	0.00353	70.48	73.1	76.08	0.00499	93.92	98.17	101.9
40%	5.5696	8.26	0.00353	70.46	73.08	76.07	0.00499	93.9	98.15	101.8
45%	7.049025	8.555	0.00353	70.44	73.06	76.06	0.00499	93.88	98.12	101.8
50%	8.7025	8.85	0.00353	70.42	73.04	76.05	0.00499	93.86	98.1	101.8

Table J.22. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 2387 kN and 2671 kN.

			P=2387 kN (240, 270, 290 kN)				P=2671 kN (270, 300, 320 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00605	109.7	115	119.8	0.00741	127.9	135.5	141.4
45%	7.049025	3.245	0.00605	109.6	115	119.7	0.00741	127.9	135.4	141.3
40%	5.5696	3.54	0.00605	109.6	115	119.7	0.00741	127.9	135.4	141.3
35%	4.264225	3.835	0.00605	109.6	114.9	119.7	0.00741	127.9	135.4	141.3
30%	3.1329	4.13	0.00605	109.6	114.9	119.6	0.0074	127.8	135.3	141.2
25%	2.175625	4.425	0.00604	109.5	114.9	119.6	0.0074	127.8	135.3	141.2
20%	1.3924	4.72	0.00604	109.5	114.9	119.6	0.0074	127.8	135.3	141.2
15%	0.783225	5.015	0.00604	109.5	114.8	119.5	0.0074	127.8	135.2	141.1
10%	0.3481	5.31	0.00604	109.5	114.8	119.5	0.00738	127.6	135	140.9
5%	0.087025	5.605	0.00604	109.4	114.8	119.5	0.00738	127.6	135	140.9
0%	0	5.9	0.00603	109.4	114.7	119.5	0.00737	127.6	135	140.9
5%	0.087025	6.195	0.00603	109.4	114.7	119.4	0.00737	127.6	134.9	140.8
10%	0.3481	6.49	0.00601	109.2	114.5	119.2	0.00737	127.5	134.9	140.8
15%	0.783225	6.785	0.00601	109.2	114.5	119.2	0.00737	127.5	134.9	140.7
20%	1.3924	7.08	0.00601	109.1	114.5	119.1	0.00737	127.5	134.8	140.7
25%	2.175625	7.375	0.00601	109.1	114.4	119.1	0.00736	127.4	134.8	140.7
30%	3.1329	7.67	0.00601	109.1	114.4	119.1	0.00736	127.4	134.8	140.6
35%	4.264225	7.965	0.006	109.1	114.4	119.1	0.00736	127.4	134.7	140.6
40%	5.5696	8.26	0.006	109	114.3	119	0.00736	127.4	134.7	140.6
45%	7.049025	8.555	0.006	109	114.3	119	0.00735	127.3	134.7	140.5
50%	8.7025	8.85	0.006	109	114.3	119	0.00735	127.3	134.6	140.5

Table J.23(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 1725 kN and 2138 kN.

		P=1725 kN		P=2138 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	0.00E+00	0.000%
10%	0.3481	0.00E+00	0.000%	0.00E+00	0.000%
15%	0.783225	0.00E+00	0.000%	2.50E-11	0.100%
20%	1.3924	2.50E-11	0.141%	2.50E-11	0.100%
25%	2.175625	2.50E-11	0.141%	1.00E-10	0.200%
30%	3.1329	2.50E-11	0.141%	1.00E-10	0.200%
35%	4.264225	1.00E-10	0.282%	1.00E-10	0.200%
40%	5.5696	1.00E-10	0.282%	1.00E-10	0.200%
45%	7.049025	1.00E-10	0.282%	1.00E-10	0.200%
50%	8.7025	1.00E-10	0.282%	2.25E-10	0.300%

Table J.23(b) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 2387 kN and 2671 kN.

		P=2387 kN		P=2671 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	2.50E-11	0.083%	2.50E-11	0.068%
10%	0.3481	2.25E-10	0.249%	2.50E-11	0.068%
15%	0.783225	2.25E-10	0.249%	2.25E-10	0.204%
20%	1.3924	2.25E-10	0.249%	2.25E-10	0.204%
25%	2.175625	2.25E-10	0.249%	4.00E-10	0.271%
30%	3.1329	4.00E-10	0.332%	4.00E-10	0.271%
35%	4.264225	6.25E-10	0.415%	6.25E-10	0.339%
40%	5.5696	6.25E-10	0.415%	6.25E-10	0.339%
45%	7.049025	6.25E-10	0.415%	9.00E-10	0.407%
50%	8.7025	6.25E-10	0.415%	9.00E-10	0.407%

Table J.24(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 1725 kN.

		P=1725 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.0004	0.0004	0.0001	0.03%	0.03%	0.01%
10%	0.3481	0.001225	0.002025	0.000225	0.05%	0.06%	0.02%
15%	0.783225	0.003025	0.004225	0.000625	0.08%	0.09%	0.03%
20%	1.3924	0.005625	0.007225	0.001225	0.11%	0.12%	0.05%
25%	2.175625	0.009025	0.011025	0.00064	0.13%	0.14%	0.03%
30%	3.1329	0.0121	0.015625	0.0025	0.16%	0.17%	0.07%
35%	4.264225	0.0169	0.021025	0.0036	0.18%	0.20%	0.08%
40%	5.5696	0.021025	0.027225	0.004225	0.21%	0.23%	0.09%
45%	7.049025	0.027225	0.034225	0.0049	0.23%	0.25%	0.09%
50%	8.7025	0.034225	0.042025	0.007225	0.26%	0.28%	0.11%

Table J.24(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 2138 kN.

		P=2138 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.0004	0.000625	0.0025	0.02%	0.03%	0.05%
10%	0.3481	0.002025	0.002025	0.0025	0.05%	0.05%	0.05%
15%	0.783225	0.0049	0.005625	0.0025	0.07%	0.08%	0.05%
20%	1.3924	0.0081	0.009025	0.0225	0.10%	0.10%	0.15%
25%	2.175625	0.0121	0.015625	0.0225	0.12%	0.13%	0.15%
30%	3.1329	0.018225	0.021025	0.0225	0.14%	0.15%	0.15%
35%	4.264225	0.0256	0.030625	0.0225	0.17%	0.18%	0.15%
40%	5.5696	0.0324	0.038025	0.0625	0.19%	0.20%	0.25%
45%	7.049025	0.04	0.0484	0.0625	0.21%	0.22%	0.25%
50%	8.7025	0.050625	0.060025	0.0625	0.24%	0.25%	0.25%

Table J.24(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 2387 kN.

		P=2387 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0	0.0025	0.0025	0.00%	0.04%	0.04%
10%	0.3481	0.0225	0.0225	0.0225	0.14%	0.13%	0.13%
15%	0.783225	0.0225	0.0225	0.0225	0.14%	0.13%	0.13%
20%	1.3924	0.04	0.04	0.0625	0.18%	0.17%	0.21%
25%	2.175625	0.04	0.0625	0.0625	0.18%	0.22%	0.21%
30%	3.1329	0.0625	0.0625	0.0625	0.23%	0.22%	0.21%
35%	4.264225	0.0625	0.0625	0.09	0.23%	0.22%	0.25%
40%	5.5696	0.09	0.1225	0.1225	0.27%	0.31%	0.29%
45%	7.049025	0.09	0.1225	0.1225	0.27%	0.31%	0.29%
50%	8.7025	0.1225	0.1225	0.16	0.32%	0.31%	0.33%

Table J.24(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and lateral load 2671 kN.

		P=2671 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0	0.0025	0.0025	0.00%	0.04%	0.04%
10%	0.3481	0.0025	0.0025	0.0025	0.04%	0.04%	0.04%
15%	0.783225	0.0225	0.0225	0.04	0.12%	0.11%	0.14%
20%	1.3924	0.0225	0.0625	0.0625	0.12%	0.19%	0.18%
25%	2.175625	0.04	0.0625	0.0625	0.16%	0.19%	0.18%
30%	3.1329	0.04	0.0625	0.09	0.16%	0.19%	0.21%
35%	4.264225	0.0625	0.1225	0.1225	0.20%	0.26%	0.25%
40%	5.5696	0.0625	0.1225	0.1225	0.20%	0.26%	0.25%
45%	7.049025	0.09	0.1225	0.16	0.24%	0.26%	0.28%
50%	8.7025	0.09	0.2025	0.2025	0.24%	0.33%	0.32%

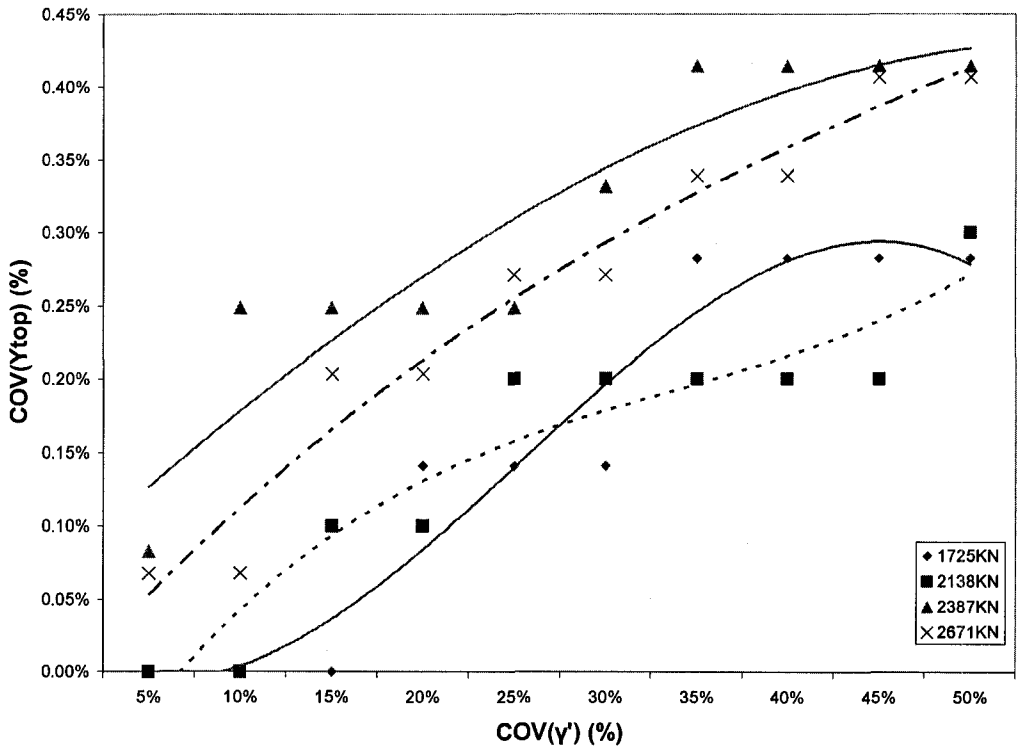

Fig. J.11 COV(Y_{Top}) for varying COV(γ') in fixed head long (10T) pile group with spacing (4D).

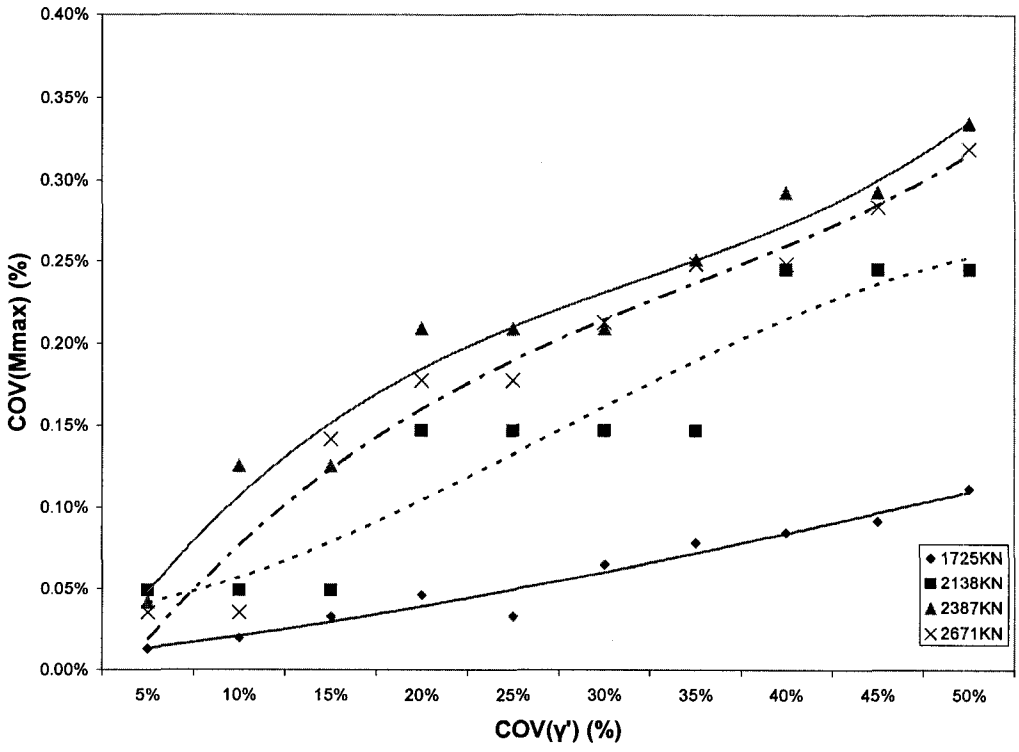

Fig. J.12(a) COV(M_{Max}) for varying COV(γ') for pile C in fixed head long pile group with spacing (4D).

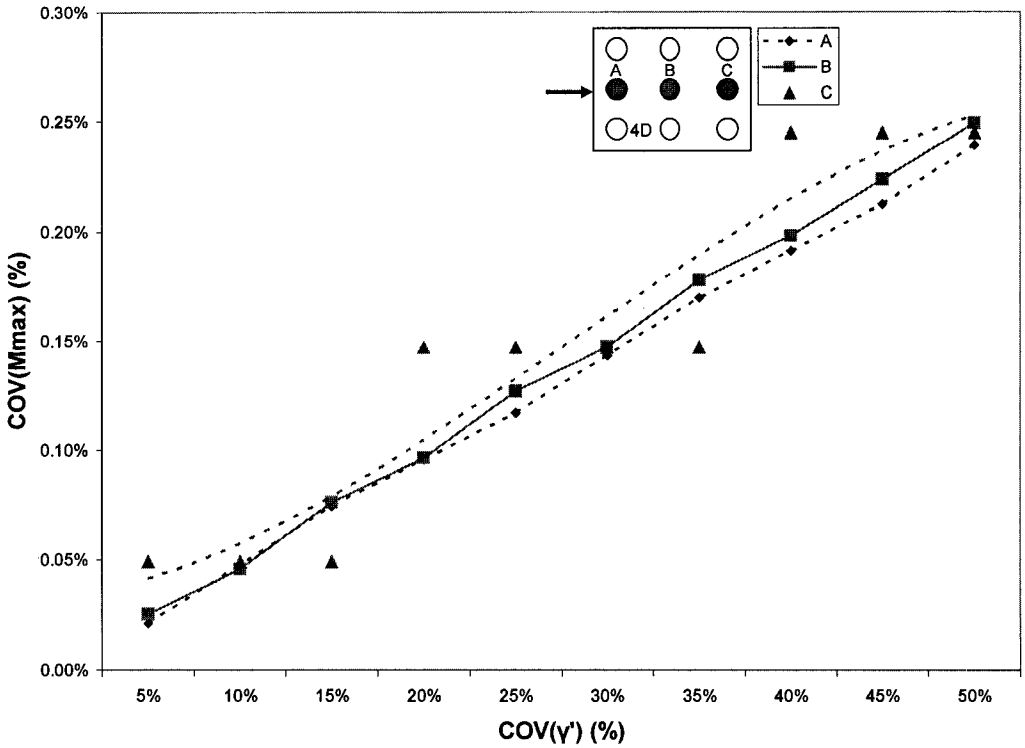

Fig. J.12 COV(M_{Max}) for varying COV(γ') for pile rows A, B, and C in fixed head long (10T) pile group with spacing (4D) at the optimum lateral load 2138 kN.

J.2 Reliability analysis of fixed head long pile (10T) group with spacing (4D)

J.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 1725 kN

$g(Y_{top})^o = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00946$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06\ m^2$

Table J.25 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 1725 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	4.22E-09	6.76E-06	3.64	3.06E-08	6.79E-06	3.63
10%	6.76E-06	1.82E-08	6.78E-06	3.63	1.23E-07	6.88E-06	3.61
15%	6.76E-06	4.41E-08	6.80E-06	3.63	2.86E-07	7.05E-06	3.56
20%	6.76E-06	8.41E-08	6.84E-06	3.62	5.11E-07	7.27E-06	3.51
25%	6.76E-06	1.41E-07	6.90E-06	3.60	8.46E-07	7.61E-06	3.43
30%	6.76E-06	2.03E-07	6.96E-06	3.59	1.29E-06	8.05E-06	3.33
35%	6.76E-06	3.08E-07	7.07E-06	3.56	1.93E-06	8.69E-06	3.21
40%	6.76E-06	5.33E-07	7.29E-06	3.50	2.84E-06	9.60E-06	3.05
45%	6.76E-06	Failed	Failed	Failed	4.20E-06	1.10E-05	2.86
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table J.26 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1725 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	4.90E-09	6.76E-06	3.64	7.23E-09	6.77E-06	3.64
10%	6.76E-06	2.10E-08	6.78E-06	3.63	2.89E-08	6.79E-06	3.63
15%	6.76E-06	4.41E-08	6.80E-06	3.63	6.76E-08	6.83E-06	3.62
20%	6.76E-06	8.12E-08	6.84E-06	3.62	1.26E-07	6.89E-06	3.61
25%	6.76E-06	1.33E-07	6.89E-06	3.60	1.98E-07	6.96E-06	3.59
30%	6.76E-06	1.89E-07	6.95E-06	3.59	2.97E-07	7.06E-06	3.56
35%	6.76E-06	2.60E-07	7.02E-06	3.57	4.36E-07	7.20E-06	3.53
40%	6.76E-06	3.36E-07	7.10E-06	3.55	6.08E-07	7.37E-06	3.49
45%	6.76E-06	4.36E-07	7.20E-06	3.53	8.28E-07	7.59E-06	3.43
50%	6.76E-06	5.26E-07	7.29E-06	3.50	1.12E-06	7.88E-06	3.37

Table J.27 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 1725 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
10%	6.76E-06	0.00E+00	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
15%	6.76E-06	0.00E+00	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
20%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
25%	6.76E-06	2.50E-11	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
30%	6.76E-06	2.50E-11	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
35%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
40%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
45%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
50%	6.76E-06	1.00E-10	6.76E-06	3.64	1.00E-10	6.76E-06	3.64

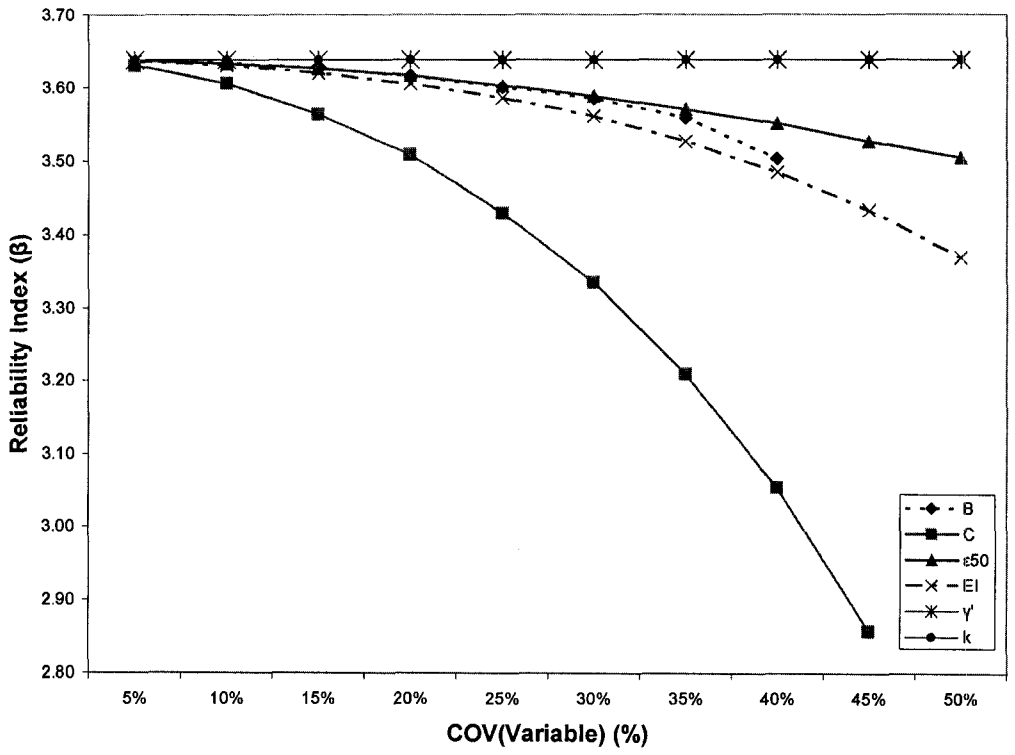

Fig. J.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (4D) at 1725 kN lateral load.

For lateral load 2138 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.008 \text{ m}$$

Table J.28 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 2138 kN.

	B			C		
VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
6.76E-06	1.00E-08	6.77E-06	3.07	6.25E-08	6.82E-06	3.06
6.76E-06	5.06E-08	6.81E-06	3.07	2.65E-07	7.03E-06	3.02
6.76E-06	1.26E-07	6.89E-06	3.05	6.16E-07	7.38E-06	2.95
6.76E-06	2.45E-07	7.01E-06	3.02	1.18E-06	7.94E-06	2.84
6.76E-06	4.42E-07	7.20E-06	2.98	2.00E-06	8.76E-06	2.70
6.76E-06	6.97E-07	7.46E-06	2.93	3.22E-06	9.98E-06	2.53
6.76E-06	1.17E-06	7.93E-06	2.84	4.86E-06	1.16E-05	2.35
6.76E-06	2.15E-06	8.91E-06	2.68	7.37E-06	1.41E-05	2.13
6.76E-06	Failed	Failed	Failed	1.13E-05	1.80E-05	1.88
6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table J.29 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 2138 kN.

	ε_{50}			EI		
VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
6.76E-06	1.10E-08	6.77E-06	3.07	1.44E-08	6.77E-06	3.07
6.76E-06	4.00E-08	6.80E-06	3.07	6.25E-08	6.82E-06	3.06
6.76E-06	8.70E-08	6.85E-06	3.06	1.48E-07	6.91E-06	3.04
6.76E-06	1.44E-07	6.90E-06	3.04	2.70E-07	7.03E-06	3.02
6.76E-06	2.26E-07	6.99E-06	3.03	4.36E-07	7.20E-06	2.98
6.76E-06	3.31E-07	7.09E-06	3.00	6.64E-07	7.42E-06	2.94
6.76E-06	4.56E-07	7.22E-06	2.98	9.60E-07	7.72E-06	2.88
6.76E-06	5.93E-07	7.35E-06	2.95	1.35E-06	8.11E-06	2.81
6.76E-06	7.57E-07	7.52E-06	2.92	1.85E-06	8.61E-06	2.73
6.76E-06	9.51E-07	7.71E-06	2.88	2.53E-06	9.29E-06	2.62

Table J.30 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 2138 kN.

	γ'			k		
VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
6.76E-06	0.00E+00	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	0.00E+00	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	2.50E-11	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	2.50E-11	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
6.76E-06	2.25E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08

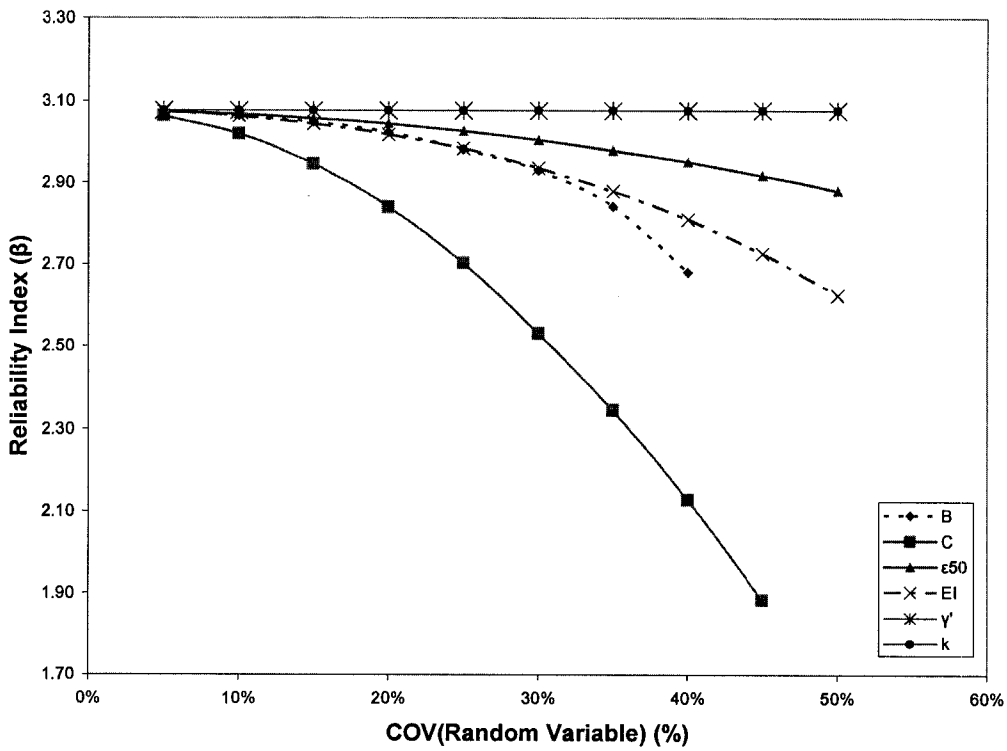

Fig. J.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (4D) at 2138 kN lateral load.

For lateral load 2387 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00697 \text{ m}$$

Table J.31 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 2387 kN.

	B			C		
VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
6.76E-06	2.40E-08	6.78E-06	2.68	1.06E-07	6.87E-06	2.66
6.76E-06	1.09E-07	6.87E-06	2.66	4.36E-07	7.20E-06	2.60
6.76E-06	2.65E-07	7.03E-06	2.63	1.04E-06	7.80E-06	2.50
6.76E-06	5.18E-07	7.28E-06	2.58	1.99E-06	8.75E-06	2.36
6.76E-06	9.22E-07	7.68E-06	2.51	3.35E-06	1.01E-05	2.19
6.76E-06	1.51E-06	8.27E-06	2.42	5.36E-06	1.21E-05	2.00
6.76E-06	2.62E-06	9.38E-06	2.28	8.32E-06	1.51E-05	1.79
6.76E-06	6.43E-06	1.32E-05	1.92	1.31E-05	1.98E-05	1.57
6.76E-06	Failed	Failed	Failed	2.10E-05	2.78E-05	1.32
6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table J.32 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 2387 kN.

	ε_{50}			EI		
VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
6.76E-06	9.02E-09	6.77E-06	2.68	2.89E-08	6.79E-06	2.68
6.76E-06	4.41E-08	6.80E-06	2.67	1.12E-07	6.87E-06	2.66
6.76E-06	1.06E-07	6.87E-06	2.66	2.45E-07	7.01E-06	2.63
6.76E-06	1.85E-07	6.94E-06	2.64	4.36E-07	7.20E-06	2.60
6.76E-06	2.81E-07	7.04E-06	2.63	7.14E-07	7.47E-06	2.55
6.76E-06	4.10E-07	7.17E-06	2.60	1.09E-06	7.85E-06	2.49
6.76E-06	5.78E-07	7.34E-06	2.57	1.56E-06	8.32E-06	2.42
6.76E-06	7.48E-07	7.51E-06	2.54	2.19E-06	8.95E-06	2.33
6.76E-06	9.51E-07	7.71E-06	2.51	3.03E-06	9.79E-06	2.23
6.76E-06	1.19E-06	7.95E-06	2.47	4.16E-06	1.09E-05	2.11

Table J.33 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 2387 kN.

	γ'			k		
VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
6.76E-06	2.50E-11	6.76E-06	2.68	2.50E-11	6.76E-06	2.68
6.76E-06	2.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	2.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	2.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	2.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	4.00E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	6.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	6.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	6.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68
6.76E-06	6.25E-10	6.76E-06	2.68	1.00E-10	6.76E-06	2.68

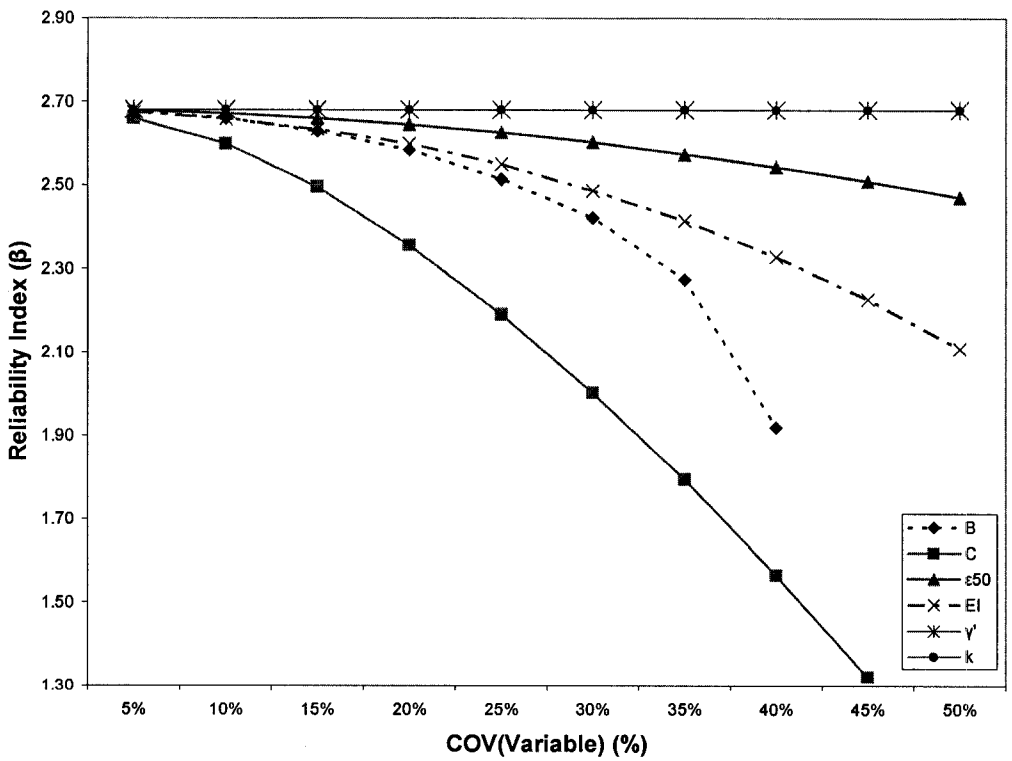

Fig. J.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (4D) at 2387 kN lateral load.

For lateral load 2671 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00563 \text{ m}$$

Table J.34 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 2671 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	5.29E-08	6.81E-06	2.16	1.85E-07	6.94E-06	2.14
10%	6.76E-06	2.40E-07	7.00E-06	2.13	7.74E-07	7.53E-06	2.05
15%	6.76E-06	6.08E-07	7.37E-06	2.07	1.81E-06	8.57E-06	1.92
20%	6.76E-06	1.19E-06	7.95E-06	2.00	3.44E-06	1.02E-05	1.76
25%	6.76E-06	2.18E-06	8.94E-06	1.88	6.08E-06	1.28E-05	1.57
30%	6.76E-06	4.10E-06	1.09E-05	1.71	9.80E-06	1.66E-05	1.38
35%	6.76E-06	1.25E-05	1.93E-05	1.28	1.63E-05	2.30E-05	1.17
40%	6.76E-06	Failed	Failed	Failed	2.79E-05	3.46E-05	0.96
45%	6.76E-06	Failed	Failed	Failed	5.36E-05	6.03E-05	0.72
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table J.35 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}' and 'EI' and applied lateral load 2671 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.32E-08	6.77E-06	2.16	4.41E-08	6.80E-06	2.16
10%	6.76E-06	5.76E-08	6.82E-06	2.16	1.81E-07	6.94E-06	2.14
15%	6.76E-06	1.26E-07	6.89E-06	2.15	4.16E-07	7.18E-06	2.10
20%	6.76E-06	2.21E-07	6.98E-06	2.13	7.40E-07	7.50E-06	2.06
25%	6.76E-06	3.42E-07	7.10E-06	2.11	1.21E-06	7.97E-06	1.99
30%	6.76E-06	4.90E-07	7.25E-06	2.09	1.86E-06	8.62E-06	1.92
35%	6.76E-06	6.89E-07	7.45E-06	2.06	2.71E-06	9.47E-06	1.83
40%	6.76E-06	8.93E-07	7.65E-06	2.04	3.88E-06	1.06E-05	1.73
45%	6.76E-06	1.14E-06	7.90E-06	2.00	5.41E-06	1.22E-05	1.61
50%	6.76E-06	1.43E-06	8.19E-06	1.97	7.43E-06	1.42E-05	1.49

Table J.36 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 2671 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
10%	6.76E-06	2.50E-11	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
15%	6.76E-06	2.25E-10	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
20%	6.76E-06	2.25E-10	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
25%	6.76E-06	4.00E-10	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
30%	6.76E-06	4.00E-10	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
35%	6.76E-06	6.25E-10	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
40%	6.76E-06	6.25E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17
45%	6.76E-06	9.00E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17
50%	6.76E-06	9.00E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17

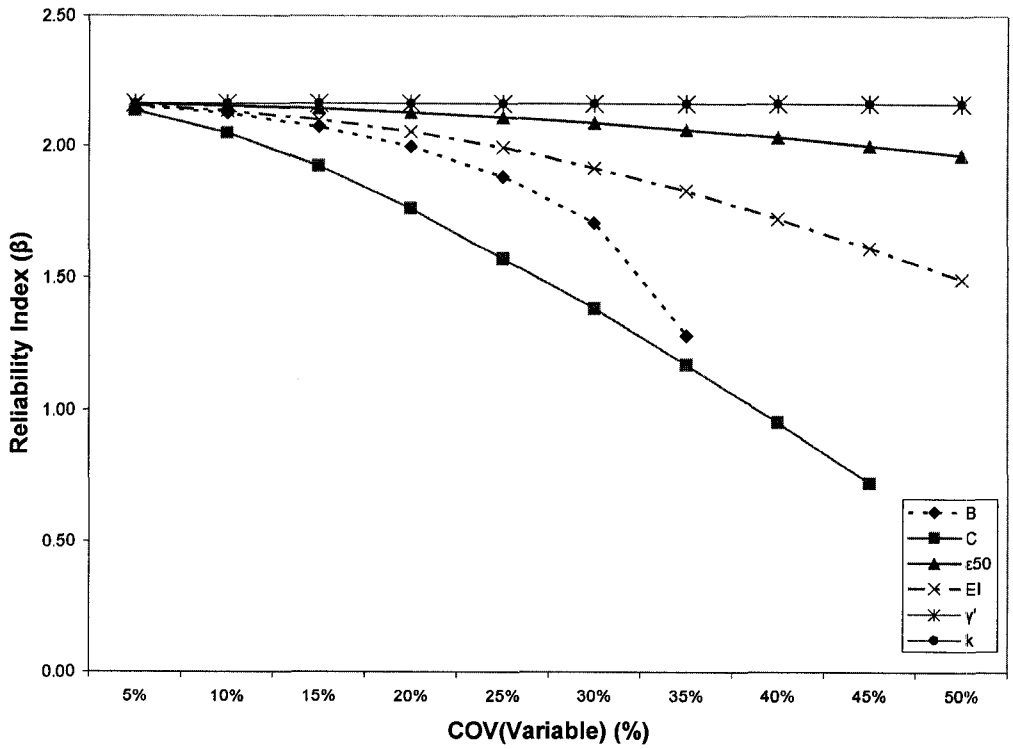

Fig. J.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (4D) at 2671 kN lateral load.

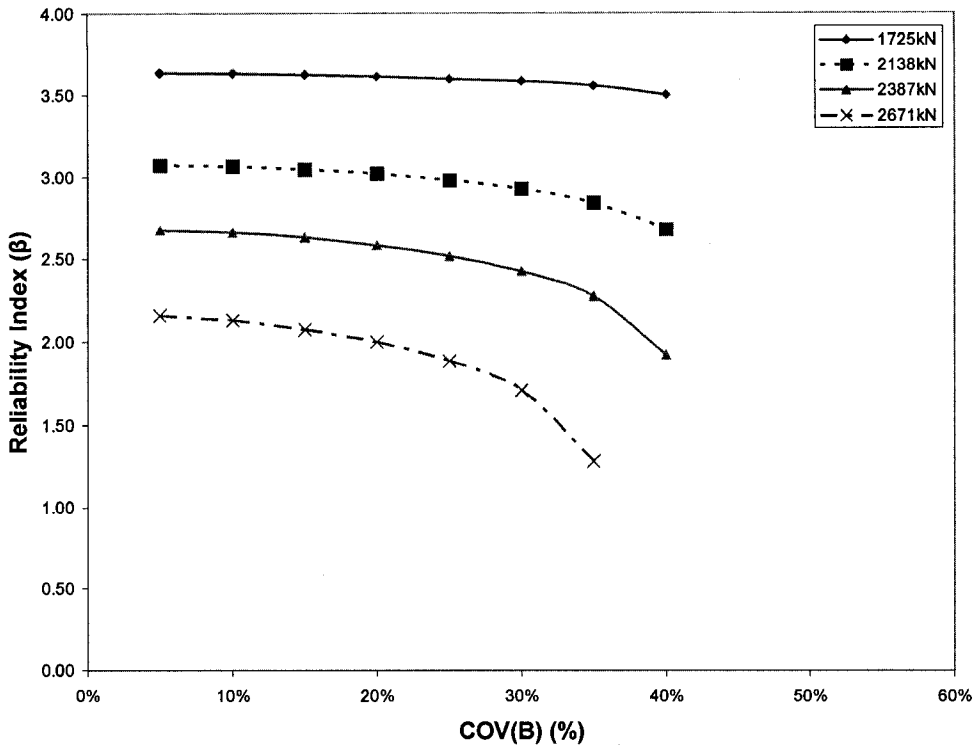

Fig. J.17 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'B'.

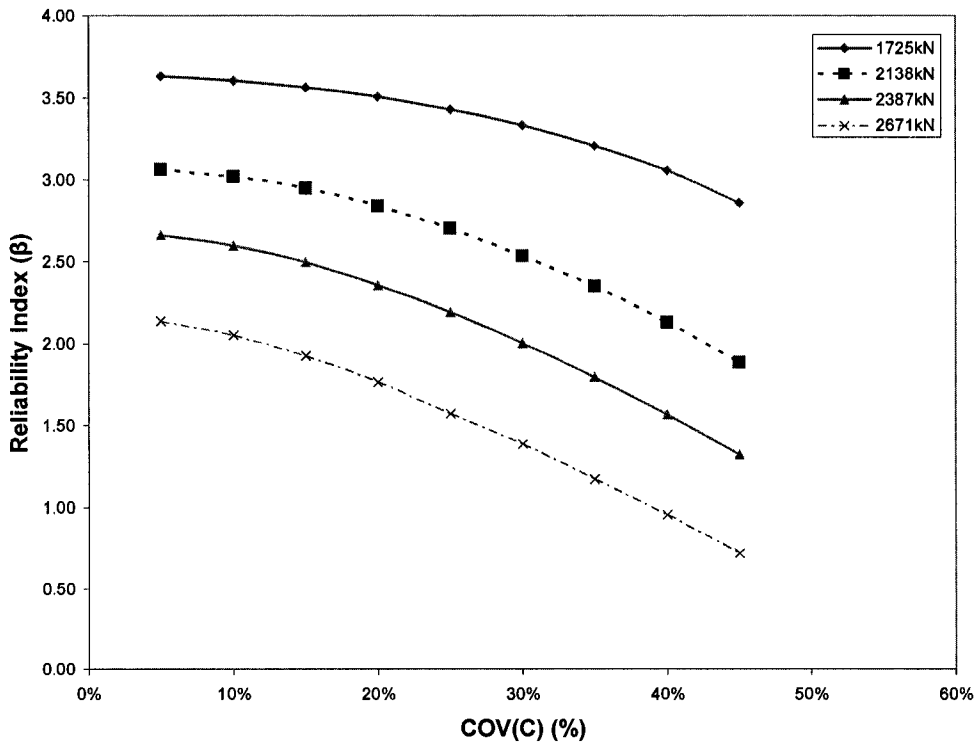

Fig. J.18 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'C'.

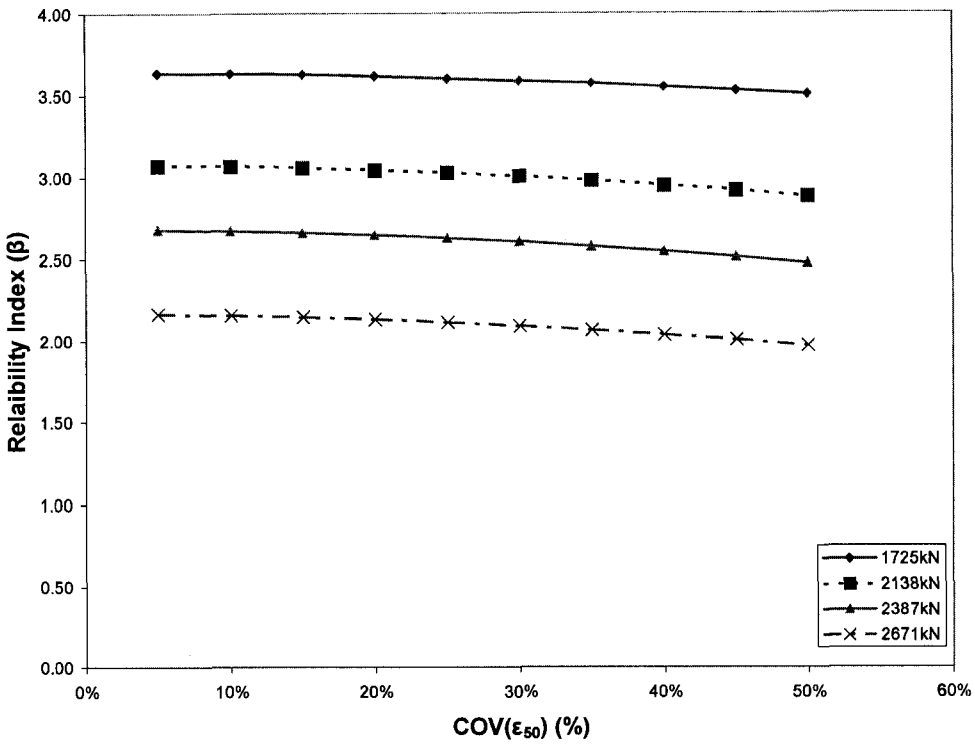

Fig. J.19 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}'.

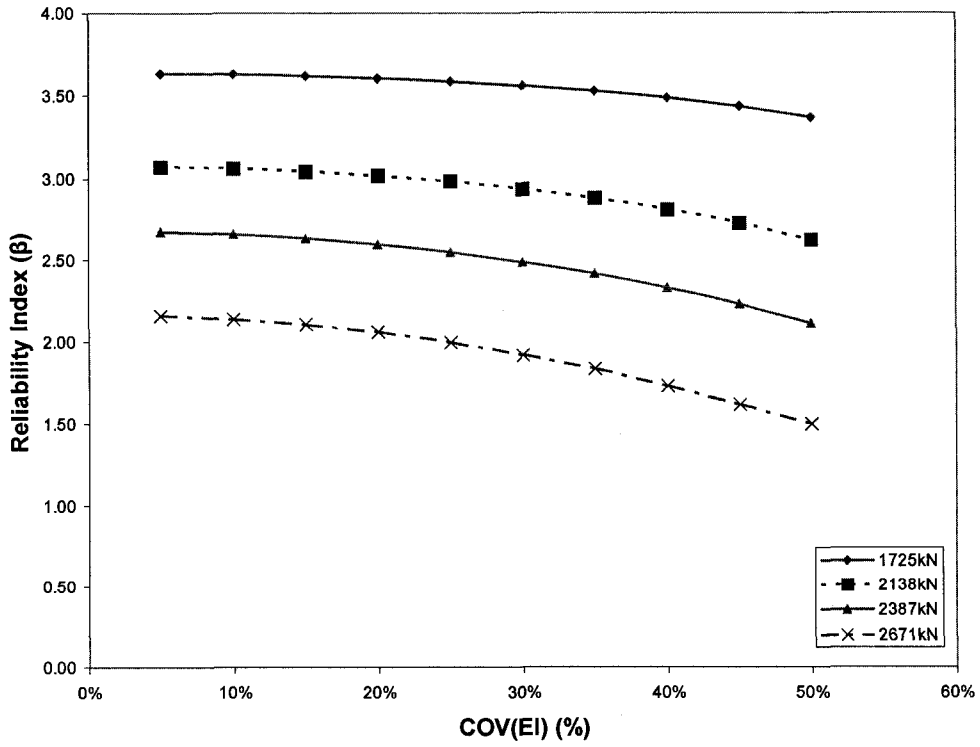

Fig. J.20 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'EI'.

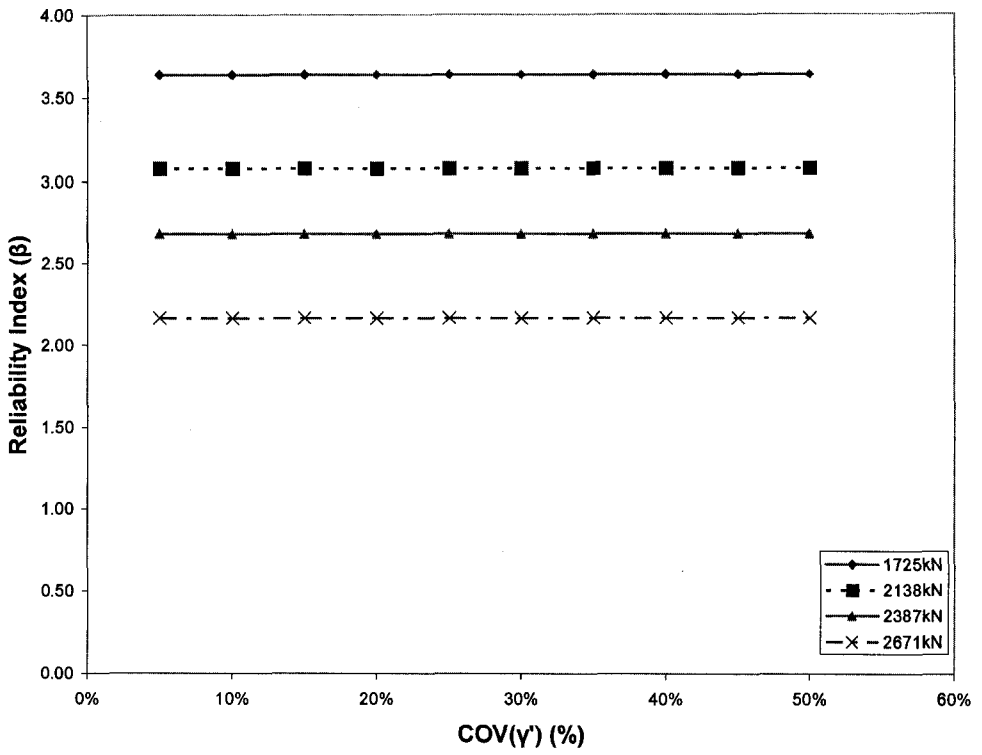

Fig. J.21 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'γ''.

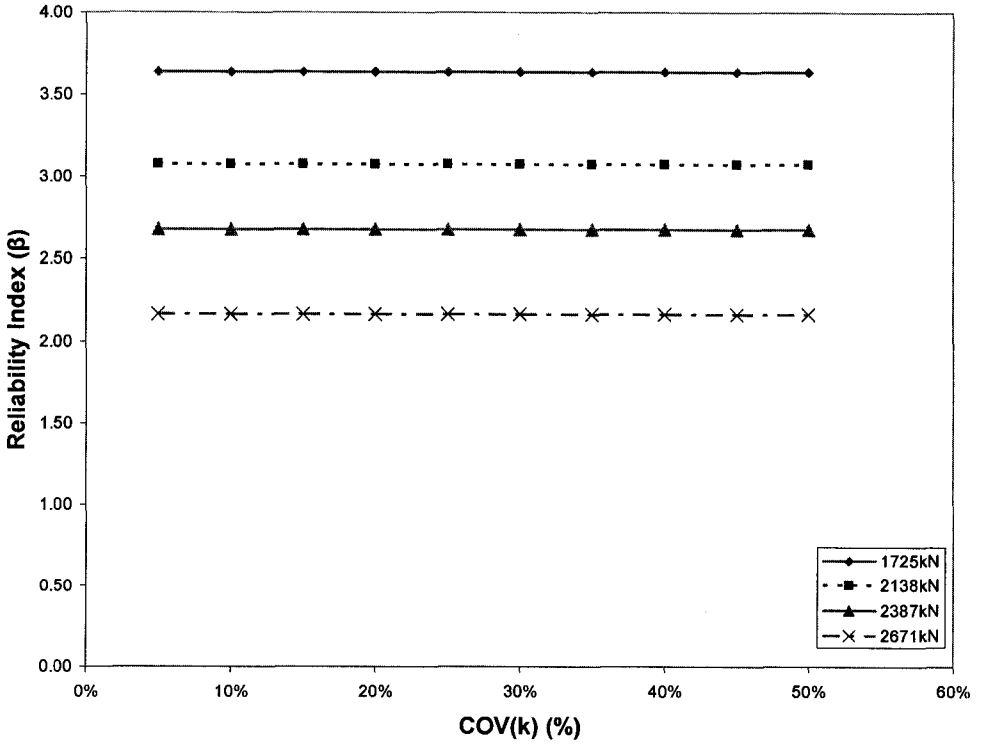

Fig. J.22 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (4D) and with varying 'k'.

J.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 1725 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 817.86 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table J.37 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 1725 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.443	4.57	0.255025	31969.695	4.57
10%	31969.44	0.024025	31969.464	4.57	2.1025	31971.543	4.57
15%	31969.44	0.2025	31969.643	4.57	6.125625	31975.566	4.57
20%	31969.44	0.6084	31970.048	4.57	12.780625	31982.221	4.57
25%	31969.44	0.71824	31970.158	4.57	9.52576	31978.966	4.57
30%	31969.44	5.1529	31974.593	4.57	38.6884	32008.128	4.57
35%	31969.44	12.3904	31981.830	4.57	56.4001	32025.840	4.57
40%	31969.44	29.975625	31999.416	4.57	75.3424	32044.782	4.57
45%	31969.44	Failed	Failed	Failed	95.4529	32064.893	4.57
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table J.38 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 1725 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0324	31969.472	4.57	0.0196	31969.460	4.57
10%	31969.44	0.0009	31969.441	4.57	0.3844	31969.824	4.57
15%	31969.44	0.009025	31969.449	4.57	1.155625	31970.596	4.57
20%	31969.44	0.038025	31969.478	4.57	2.295225	31971.735	4.57
25%	31969.44	0.02304	31969.463	4.57	1.45924	31970.899	4.57
30%	31969.44	0.099225	31969.539	4.57	5.3361	31974.776	4.57
35%	31969.44	0.1764	31969.616	4.57	7.29	31976.730	4.57
40%	31969.44	0.297025	31969.737	4.57	9.455625	31978.896	4.57
45%	31969.44	0.4356	31969.876	4.57	11.8336	31981.274	4.57
50%	31969.44	0.390625	31969.831	4.57	14.44	31983.880	4.57

Table J.39 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 1725 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0001	31969.440	4.57	0.000625	31969.441	4.57
10%	31969.44	0.000225	31969.440	4.57	0.0016	31969.442	4.57
15%	31969.44	0.000625	31969.441	4.57	0.003025	31969.443	4.57
20%	31969.44	0.001225	31969.441	4.57	0.005625	31969.446	4.57
25%	31969.44	0.00064	31969.441	4.57	0.00576	31969.446	4.57
30%	31969.44	0.0025	31969.443	4.57	0.018225	31969.458	4.57
35%	31969.44	0.0036	31969.444	4.57	0.030625	31969.471	4.57
40%	31969.44	0.004225	31969.444	4.57	0.046225	31969.486	4.57
45%	31969.44	0.0049	31969.445	4.57	0.081225	31969.521	4.57
50%	31969.44	0.007225	31969.447	4.57	0.2025	31969.643	4.57

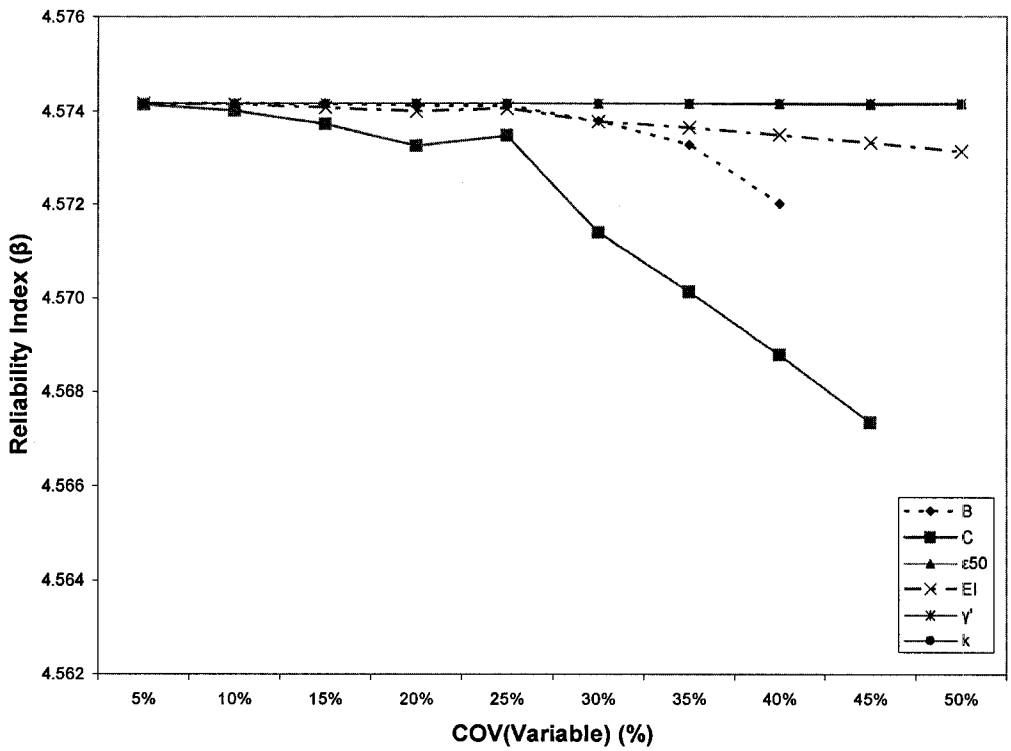

Fig. J.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (4D) at 1725 kN lateral load.

For lateral load 2138 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 792 \text{ kN.m}$$

Table J.40 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 2138 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.49	31969.93	4.43	7.8961	31977.34	4.43
10%	31969.44	2.7225	31972.16	4.43	33.64	32003.08	4.43
15%	31969.44	7.29	31976.73	4.43	58.446025	32027.89	4.43
20%	31969.44	14.8996	31984.34	4.43	82.6281	32052.07	4.42
25%	31969.44	28.09	31997.53	4.43	108.7849	32078.22	4.42
30%	31969.44	43.9569	32013.40	4.43	140.06723	32109.51	4.42
35%	31969.44	76.5625	32046.00	4.42	172.6596	32142.10	4.42
40%	31969.44	161.29	32130.73	4.42	206.92823	32176.37	4.42
45%	31969.44	Failed	Failed	Failed	232.2576	32201.70	4.41
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table J.41 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 2138 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.81	31970.25	4.43	1.5625	31971.00	4.43
10%	31969.44	3.24	31972.68	4.43	6.0025	31975.44	4.43
15%	31969.44	7.155625	31976.60	4.43	13.653025	31983.09	4.43
20%	31969.44	12.567025	31982.01	4.43	24.1081	31993.55	4.43
25%	31969.44	17.098225	31986.54	4.43	38.44	32007.88	4.43
30%	31969.44	15.6816	31985.12	4.43	43.9569	32013.40	4.43
35%	31969.44	13.875625	31983.32	4.43	46.854025	32016.29	4.43
40%	31969.44	11.9025	31981.34	4.43	50.41	32019.85	4.43
45%	31969.44	9.61	31979.05	4.43	52.2729	32021.71	4.43
50%	31969.44	8.41	31977.85	4.43	54.4644	32023.90	4.43

Table J.42 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 2138 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.43	0.0025	31969.44	4.43
10%	31969.44	0.0025	31969.44	4.43	0.0025	31969.44	4.43
15%	31969.44	0.0025	31969.44	4.43	0.0025	31969.44	4.43
20%	31969.44	0.0225	31969.46	4.43	0.0025	31969.44	4.43
25%	31969.44	0.0225	31969.46	4.43	0.0025	31969.44	4.43
30%	31969.44	0.0225	31969.46	4.43	0.0025	31969.44	4.43
35%	31969.44	0.0225	31969.46	4.43	0.0025	31969.44	4.43
40%	31969.44	0.0625	31969.50	4.43	0.01	31969.45	4.43
45%	31969.44	0.0625	31969.50	4.43	0.01	31969.45	4.43
50%	31969.44	0.0625	31969.50	4.43	0.01	31969.45	4.43

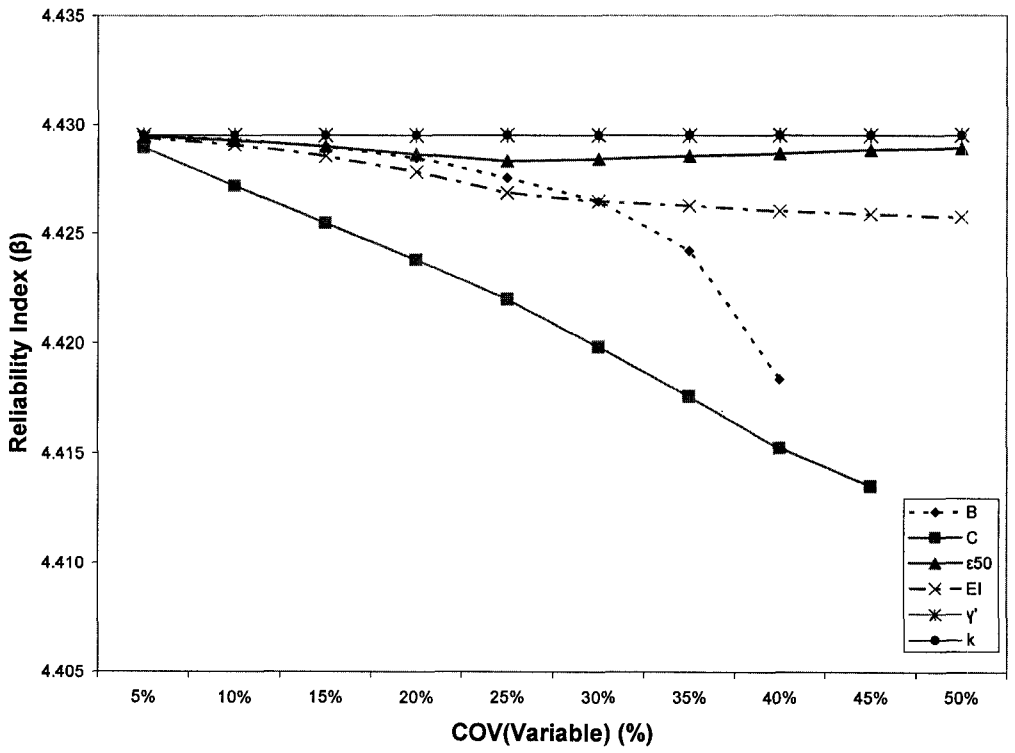

Fig. J.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group (4D) at 2138 kN lateral load.

For lateral load 2387 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 774.5 \text{ kN.m}$$

Table J.43 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 2387 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1.44	31970.88	4.33	11.2225	31980.66	4.33
10%	31969.44	7.0225	31976.46	4.33	46.9225	32016.36	4.33
15%	31969.44	17.64	31987.08	4.33	106.09	32075.53	4.32
20%	31969.44	35.4025	32004.84	4.33	176.89	32146.33	4.32
25%	31969.44	64	32033.44	4.33	213.16	32182.60	4.32
30%	31969.44	107.1225	32076.56	4.32	254.4025	32223.84	4.31
35%	31969.44	191.8225	32161.26	4.32	295.84	32265.28	4.31
40%	31969.44	499.5225	32468.96	4.30	318.6225	32288.06	4.31
45%	31969.44	Failed	Failed	Failed	462.25	32431.69	4.30
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table J.44 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 2387 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.4225	31969.86	4.33	1.1025	31970.54	4.33
10%	31969.44	2.1025	31971.54	4.33	4.84	31974.28	4.33
15%	31969.44	5.29	31974.73	4.33	12.6025	31982.04	4.33
20%	31969.44	9.3025	31978.74	4.33	23.04	31992.48	4.33
25%	31969.44	15.21	31984.65	4.33	36.6025	32006.04	4.33
30%	31969.44	22.5625	31992.00	4.33	53.29	32022.73	4.33
35%	31969.44	33.0625	32002.50	4.33	73.96	32043.40	4.33
40%	31969.44	39.69	32009.13	4.33	99.0025	32068.44	4.32
45%	31969.44	34.2225	32003.66	4.33	110.25	32079.69	4.32
50%	31969.44	27.5625	31997.00	4.33	112.36	32081.80	4.32

Table J.45 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 2387 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.33	0.0025	31969.44	4.33
10%	31969.44	0.0225	31969.46	4.33	0.0225	31969.46	4.33
15%	31969.44	0.0225	31969.46	4.33	0.0225	31969.46	4.33
20%	31969.44	0.0625	31969.50	4.33	0.0225	31969.46	4.33
25%	31969.44	0.0625	31969.50	4.33	0.0225	31969.46	4.33
30%	31969.44	0.0625	31969.50	4.33	0.04	31969.48	4.33
35%	31969.44	0.09	31969.53	4.33	0.04	31969.48	4.33
40%	31969.44	0.1225	31969.56	4.33	0.04	31969.48	4.33
45%	31969.44	0.1225	31969.56	4.33	0.04	31969.48	4.33
50%	31969.44	0.16	31969.60	4.33	0.04	31969.48	4.33

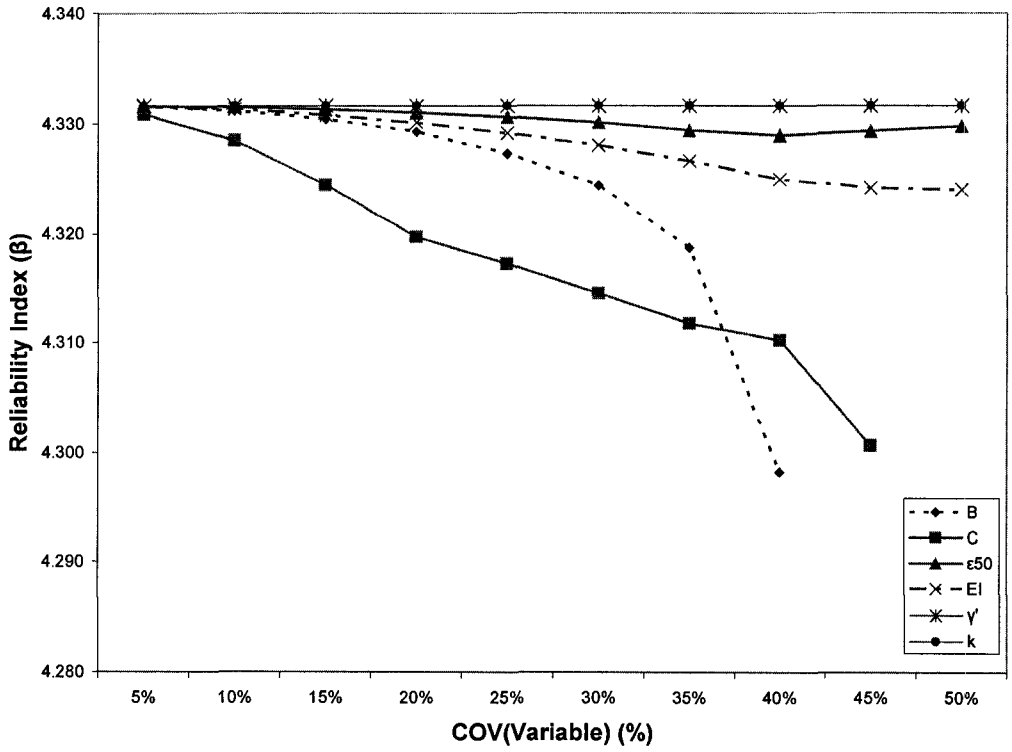

Fig. J.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (4D) at 2387 kN lateral load.

For lateral load 2671 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 753.1 \text{ kN.m}$$

Table J.46 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'B' and 'C' and applied lateral load 2671 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	3.61	31973.05	4.21	16.81	31986.25	4.21
10%	31969.44	17.2225	31986.66	4.21	65.61	32035.05	4.21
15%	31969.44	44.2225	32013.66	4.21	141.61	32111.05	4.20
20%	31969.44	85.5625	32055.00	4.21	243.36	32212.80	4.20
25%	31969.44	157.5025	32126.94	4.20	374.4225	32343.86	4.19
30%	31969.44	290.7025	32260.14	4.19	453.69	32423.13	4.18
35%	31969.44	789.61	32759.05	4.16	473.0625	32442.50	4.18
40%	31969.44	Failed	Failed	Failed	812.25	32781.69	4.16
45%	31969.44	Failed	Failed	Failed	1672.81	33642.25	4.11
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table J.47 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying ε_{50} and EI and applied lateral load 2671 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.36	31969.800	4.21	1.21	31970.650	4.21
10%	31969.44	1.5625	31971.003	4.21	4.84	31974.280	4.21
15%	31969.44	3.61	31973.050	4.21	11.2225	31980.663	4.21
20%	31969.44	5.76	31975.200	4.21	21.16	31990.600	4.21
25%	31969.44	9	31978.440	4.21	33.0625	32002.503	4.21
30%	31969.44	11.9025	31981.343	4.21	46.24	32015.680	4.21
35%	31969.44	17.2225	31986.663	4.21	62.41	32031.850	4.21
40%	31969.44	21.6225	31991.063	4.21	80.1025	32049.543	4.21
45%	31969.44	27.04	31996.480	4.21	101.0025	32070.443	4.21
50%	31969.44	32.49	32001.930	4.21	123.21	32092.650	4.20

Table J.48 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'γ'' and 'k' and applied lateral load 2671 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.21	0	31969.44	4.21
10%	31969.44	0.0025	31969.44	4.21	0.0025	31969.44	4.21
15%	31969.44	0.04	31969.48	4.21	0.0025	31969.44	4.21
20%	31969.44	0.0625	31969.50	4.21	0.0025	31969.44	4.21
25%	31969.44	0.0625	31969.50	4.21	0.01	31969.45	4.21
30%	31969.44	0.09	31969.53	4.21	0.01	31969.45	4.21
35%	31969.44	0.1225	31969.56	4.21	0.01	31969.45	4.21
40%	31969.44	0.1225	31969.56	4.21	0.01	31969.45	4.21
45%	31969.44	0.16	31969.60	4.21	0.01	31969.45	4.21
50%	31969.44	0.2025	31969.64	4.21	0.01	31969.45	4.21

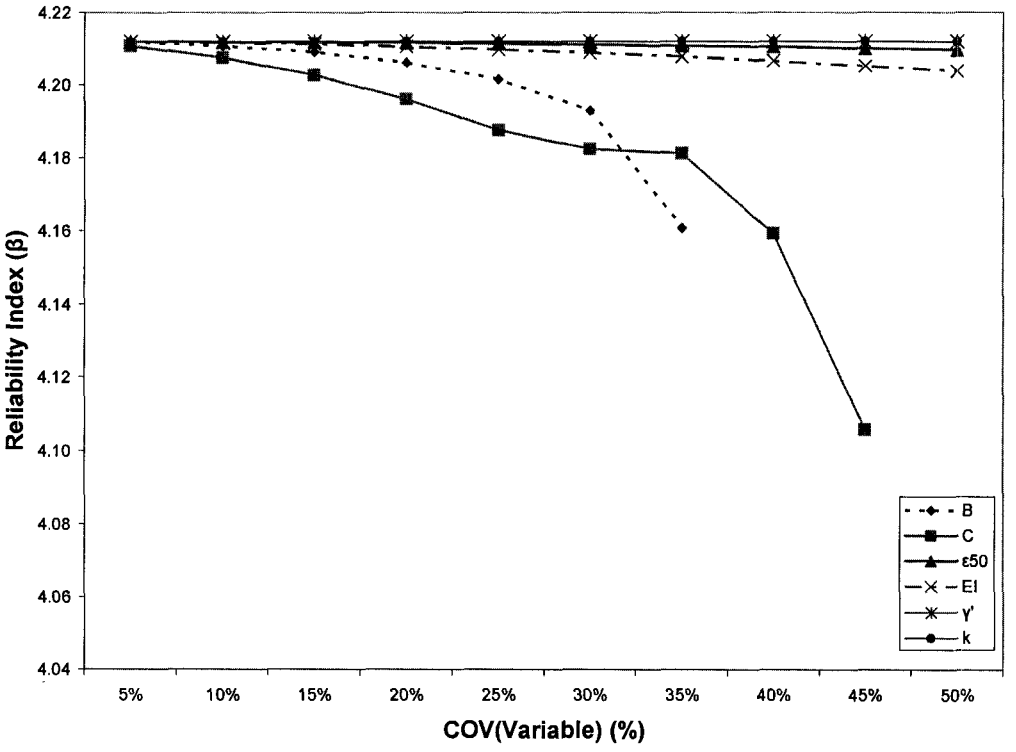

Fig. J.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (4D) at 2671 kN lateral load.

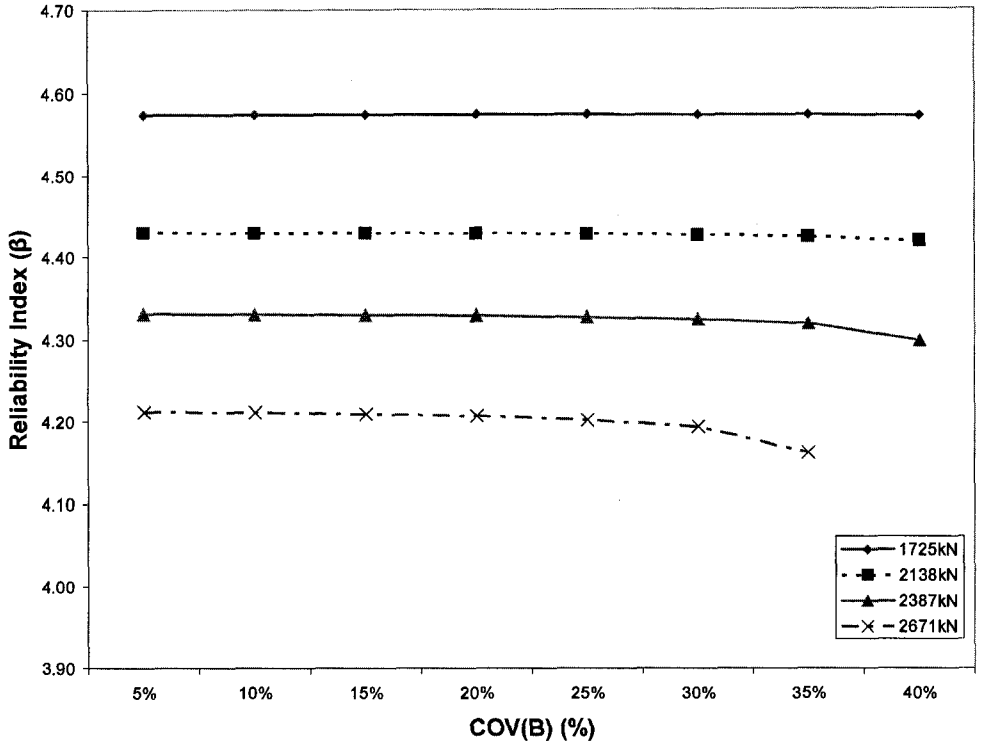

Fig. J.27 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'B'.

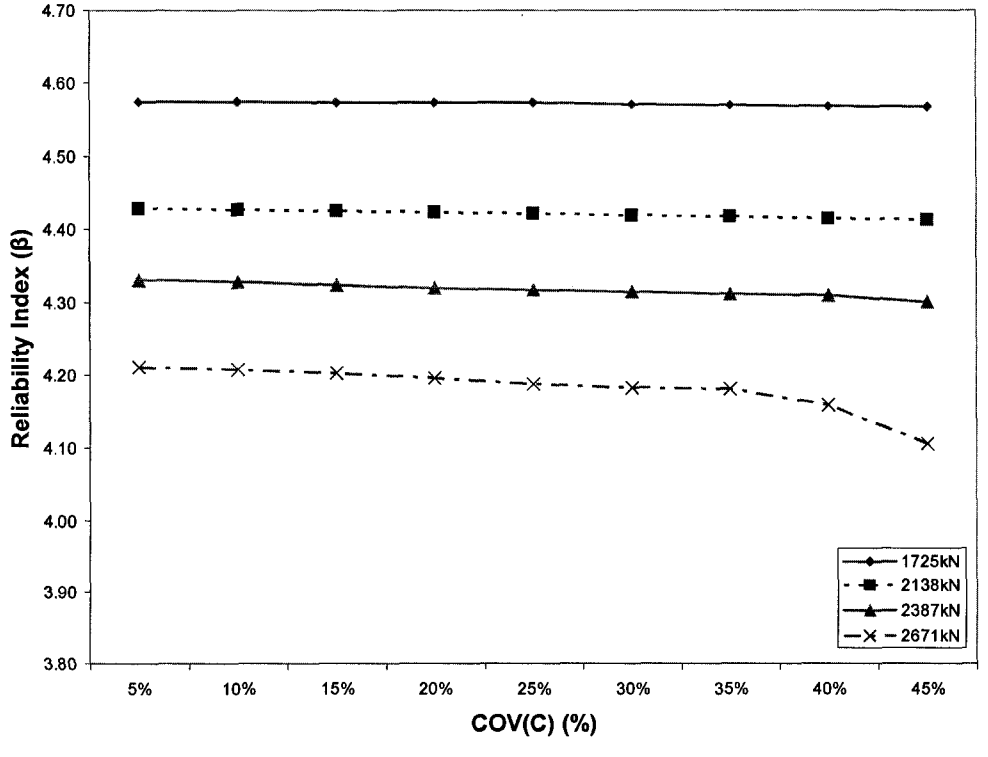

Fig. J.28 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'C'.

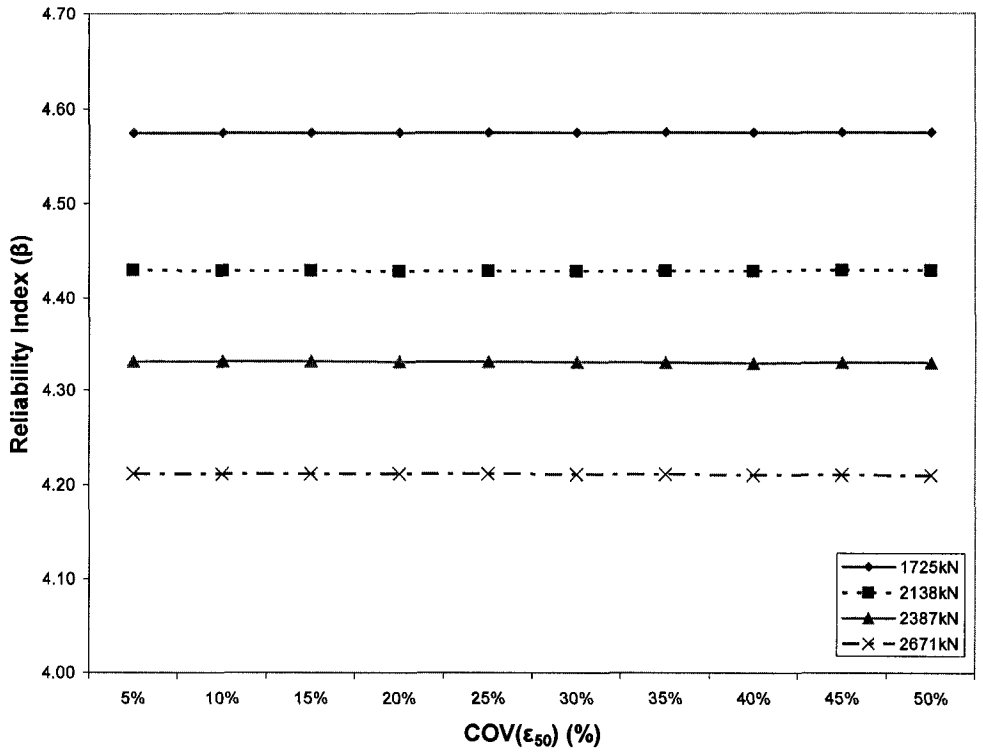

Fig. J.29 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'ε_{50}'.

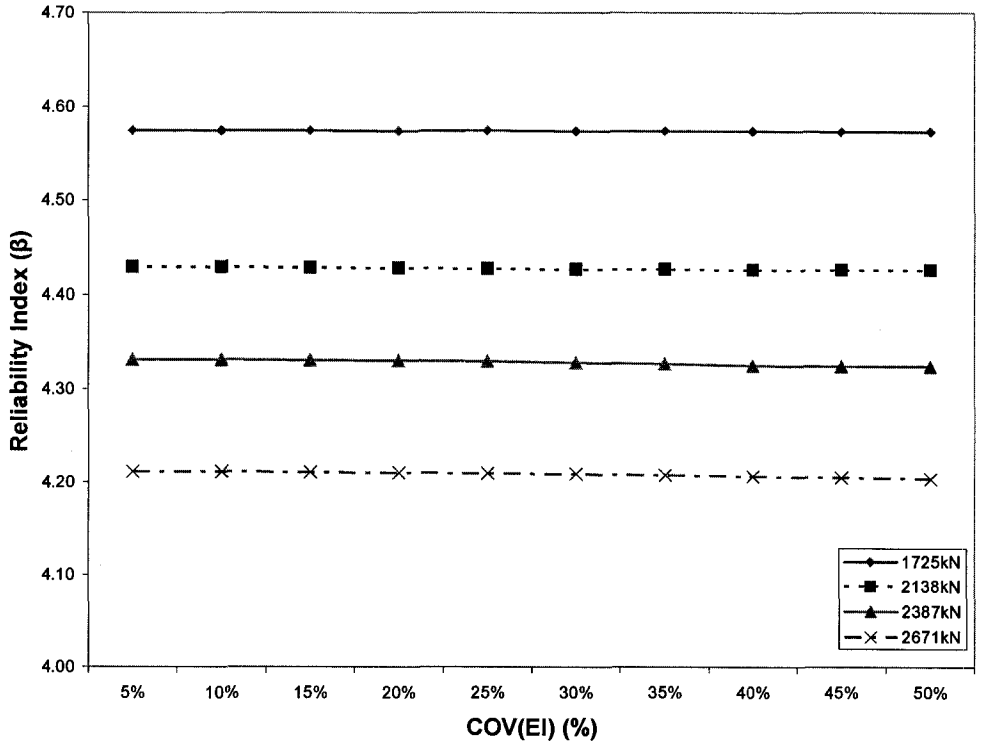

Fig. J.30 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'EI'.

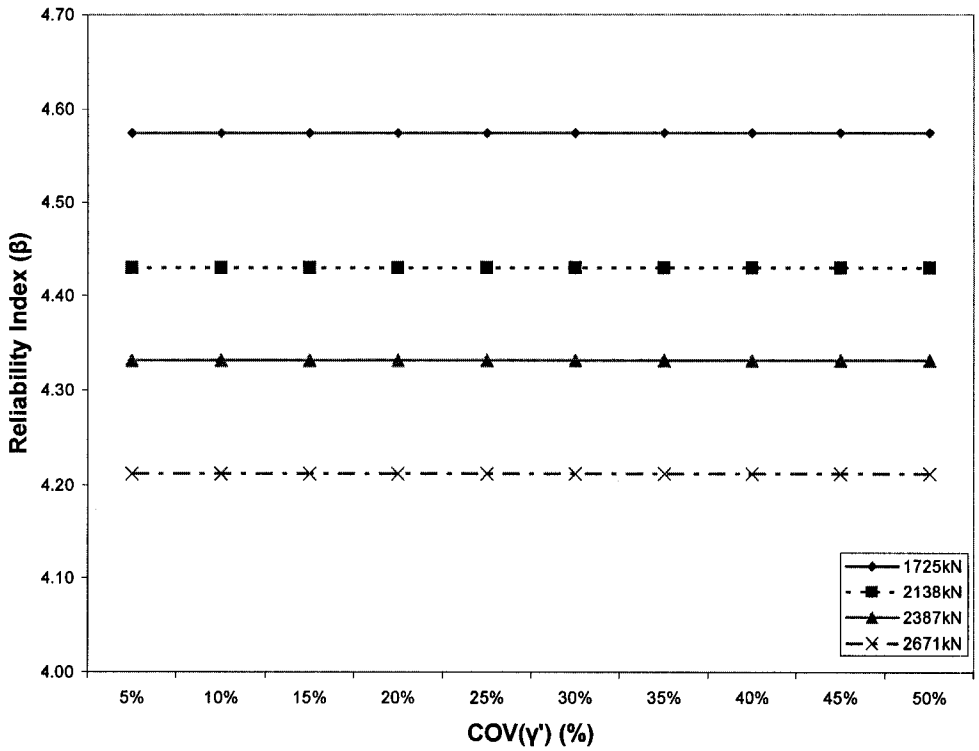

Fig. J.31 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'γ'.

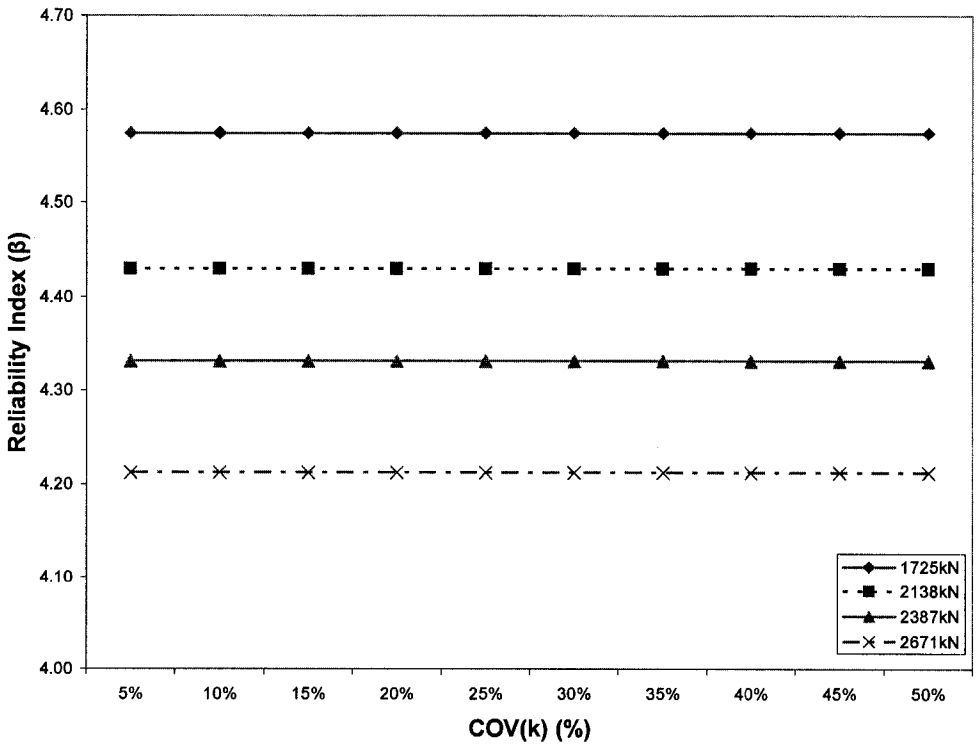

Fig. J.32 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (4D) and with varying 'k'.

APPENDIX K

LATERALLY LOADED HINGED HEAD LONG PILE GROUP

(Spacing: 5D)

K.1.1 Probabilistic modeling of laterally loaded hinged head long (10T) pile group (5D) and with 'B' as varying random design variable

Table K.1. Values of Y_{Top} and M_{Max} for rows A, B, C of free head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 685 kN and 958 kN.

			P=685 kN (74, 76, 78 kN)				P=958 kN (100, 110, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	0.00349	94.51	97.53	100.5	0.00606	131.8	136.4	141
45%	0.052258	0.2794	0.00333	94.73	97.54	100.3	0.00565	131.9	136.4	140.9
40%	0.0412902	0.3048	0.00323	94.77	97.53	100.3	0.00531	132	136.4	140.8
35%	0.0316128	0.3302	0.00314	94.75	97.51	100.3	0.00505	132.1	136.4	140.7
30%	0.0232258	0.3556	0.00305	94.75	97.52	100.3	0.00486	132.2	136.4	140.6
25%	0.016129	0.381	0.00297	94.75	97.51	100.3	0.00469	132.4	136.5	140.4
20%	0.0103226	0.4064	0.0029	94.75	97.52	100.3	0.00458	132.5	136.4	140.3
15%	0.0058064	0.4318	0.00294	94.76	97.52	100.3	0.00462	132.5	136.4	140.3
10%	0.0025806	0.4572	0.00297	94.77	97.51	100.3	0.00467	132.5	136.4	140.3
5%	0.0006452	0.4826	0.003	94.77	97.51	100.3	0.00471	132.5	136.4	140.3
0%	0	0.508	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
5%	0.0006452	0.5334	0.00304	94.78	97.51	100.3	0.00477	132.6	136.4	140.2
10%	0.0025806	0.5588	0.00306	94.79	97.51	100.3	0.0048	132.6	136.4	140.2
15%	0.0058064	0.5842	0.00308	94.8	97.51	100.3	0.00482	132.6	136.4	140.2
20%	0.0103226	0.6096	0.00309	94.8	97.51	100.3	0.00484	132.7	136.4	140.1
25%	0.016129	0.635	0.00311	94.81	97.51	100.3	0.00486	132.7	136.4	140.1
30%	0.0232258	0.6604	0.00312	94.81	97.51	100.3	0.00488	132.7	136.4	140.1
35%	0.0316128	0.6858	0.00313	94.82	97.51	100.3	0.00489	132.7	136.4	140.1
40%	0.0412902	0.7112	0.00314	94.82	97.51	100.3	0.00492	132.7	136.4	140.1
45%	0.052258	0.7366	0.00315	94.83	97.51	100.2	0.00493	132.7	136.4	140.1
50%	0.064516	0.762	0.00315	94.85	97.51	100.2	0.00493	132.7	136.4	140.1

Table K.2 Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1130 kN and 1364 kN.

			P=1130 kN (120, 130, 130 kN)				P=1364 kN (150, 150, 160 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	0.00833	155.2	160.9	166.6	0.0143	220.7	225.7	230.9
45%	0.052258	0.2794	0.00759	155.3	160.9	166.4	0.0112	193.1	196.6	201.2
40%	0.0412902	0.3048	0.00704	155.5	160.9	166.3	0.0101	187.3	194.2	201.1
35%	0.0316128	0.3302	0.00665	155.6	160.9	166.2	0.0093	187.5	194.2	200.9
30%	0.0232258	0.3556	0.00631	155.6	160.9	166.1	0.00873	187.6	194.2	200.8
25%	0.016129	0.381	0.00603	155.8	160.9	166	0.00827	187.7	194.2	200.6
20%	0.0103226	0.4064	0.00581	155.9	160.9	165.9	0.00788	187.8	194.2	200.5
15%	0.0058064	0.4318	0.00584	155.9	160.9	165.9	0.00791	187.9	194.2	200.5
10%	0.0025806	0.4572	0.00588	155.9	160.9	165.8	0.00794	187.9	194.2	200.4
5%	0.0006452	0.4826	0.00592	156	160.9	165.8	0.00796	188	194.2	200.4
0%	0	0.508	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5%	0.0006452	0.5334	0.00598	156.1	160.9	165.6	0.00798	188.1	194.2	200.3
10%	0.0025806	0.5588	0.006	156.2	160.9	165.6	0.00799	188.1	194.2	200.3
15%	0.0058064	0.5842	0.00603	156.2	160.9	165.6	0.00799	188.1	194.2	200.2
20%	0.0103226	0.6096	0.00606	156.2	160.9	165.6	0.00799	188.2	194.2	200.2
25%	0.016129	0.635	0.00608	156.2	160.9	165.5	0.00799	188.2	194.2	200.2
30%	0.0232258	0.6604	0.00609	156.2	160.9	165.5	0.00799	188.2	194.2	200.1
35%	0.0316128	0.6858	0.00611	156.3	160.9	165.5	0.00799	188.3	194.2	200.1
40%	0.0412902	0.7112	0.00612	156.3	160.9	165.5	0.00799	188.3	194.2	200
45%	0.052258	0.7366	0.00613	156.3	160.9	165.5	0.00798	188.4	194.2	200
50%	0.064516	0.762	0.00614	156.3	160.9	165.4	0.00797	188.4	194.2	200

Table K.3(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 685 kN and 958 kN.

		P=685 kN		P=958 kN	
COV(B) (%)	Var (B) (m)2	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	4.00E-10	0.662%	9.00E-10	0.633%
10%	2.58E-03	2.02E-09	1.490%	4.22E-09	1.371%
15%	5.81E-03	4.90E-09	2.318%	1.00E-08	2.110%
20%	1.03E-02	9.03E-09	3.146%	1.69E-08	2.743%
25%	1.61E-02	4.90E-09	2.318%	7.23E-09	1.793%
30%	2.32E-02	1.22E-09	1.159%	1.00E-10	0.211%
35%	3.16E-02	2.50E-11	0.166%	6.40E-09	1.688%
40%	4.13E-02	2.02E-09	1.490%	3.80E-08	4.114%
45%	5.23E-02	8.10E-09	2.980%	1.30E-07	7.595%
50%	6.45E-02	2.89E-08	5.629%	3.19E-07	11.920%

Table K.3(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1130kN and 1364kN.

		P=1130 kN		P=1364 kN	
COV(B) (%)	Var (B) (m)2	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	6.45E-04	9.00E-10	0.504%	1.00E-10	0.125%
10%	2.58E-03	3.60E-09	1.008%	6.25E-10	0.314%
15%	5.81E-03	9.03E-09	1.597%	1.60E-09	0.502%
20%	1.03E-02	1.56E-08	2.101%	3.03E-09	0.690%
25%	1.61E-02	6.25E-10	0.420%	1.96E-08	1.757%
30%	2.32E-02	1.21E-08	1.849%	1.37E-07	4.642%
35%	3.16E-02	7.29E-08	4.538%	4.29E-07	8.218%
40%	4.13E-02	2.12E-07	7.731%	1.11E-06	13.237%
45%	5.23E-02	5.33E-07	12.269%	2.59E-06	20.201%
50%	6.45E-02	1.20E-06	18.403%	1.00E-05	39.711%

Table K.4(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 685 kN.

		P=685 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	6.45E-04	2.50E-05	0.00E+00	0	0.01%	0.00%	0.00%
10%	2.58E-03	1.00E-04	0.00E+00	0	0.01%	0.00%	0.00%
15%	5.81E-03	4.00E-04	2.50E-05	0	0.02%	0.01%	0.00%
20%	1.03E-02	6.25E-04	2.50E-05	0	0.03%	0.01%	0.00%
25%	1.61E-02	9.00E-04	0.00E+00	0	0.03%	0.00%	0.00%
30%	2.32E-02	9.00E-04	2.50E-05	0	0.03%	0.01%	0.00%
35%	3.16E-02	1.22E-03	0.00E+00	0	0.04%	0.00%	0.00%
40%	4.13E-02	6.25E-04	1.00E-04	0	0.03%	0.01%	0.00%
45%	5.23E-02	2.50E-03	2.25E-04	0.0025	0.05%	0.02%	0.05%
50%	6.45E-02	2.89E-02	1.00E-04	0.0225	0.18%	0.01%	0.15%

Table K.4(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 958 kN.

		P=958 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	6.45E-04	0.0025	0	0.0025	0.04%	0.00%	0.04%
10%	2.58E-03	0.0025	0	0.0025	0.04%	0.00%	0.04%
15%	5.81E-03	0.0025	0	0.0025	0.04%	0.00%	0.04%
20%	1.03E-02	0.01	0	0.01	0.08%	0.00%	0.07%
25%	1.61E-02	0.0225	0.0025	0.0225	0.11%	0.04%	0.11%
30%	2.32E-02	0.0625	0	0.0625	0.19%	0.00%	0.18%
35%	3.16E-02	0.09	0	0.09	0.23%	0.00%	0.21%
40%	4.13E-02	0.1225	0	0.1225	0.26%	0.00%	0.25%
45%	5.23E-02	0.16	0	0.16	0.30%	0.00%	0.29%
50%	6.45E-02	0.2025	0	0.2025	0.34%	0.00%	0.32%

Table K.4(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1130 kN.

		P=1130 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	6.45E-04	0.0025	0.00E+00	0.01	0.03%	0.00%	0.06%
10%	2.58E-03	0.0225	0.00E+00	0.01	0.10%	0.00%	0.06%
15%	5.81E-03	0.0225	0.00E+00	0.0225	0.10%	0.00%	0.09%
20%	1.03E-02	0.0225	0.00E+00	0.0225	0.10%	0.00%	0.09%
25%	1.61E-02	0.04	0.00E+00	0.0625	0.13%	0.00%	0.15%
30%	2.32E-02	0.09	0.00E+00	0.09	0.19%	0.00%	0.18%
35%	3.16E-02	0.1225	0.00E+00	0.1225	0.22%	0.00%	0.21%
40%	4.13E-02	0.16	0.00E+00	0.16	0.26%	0.00%	0.24%
45%	5.23E-02	0.25	0.00E+00	0.2025	0.32%	0.00%	0.27%
50%	6.45E-02	0.3025	0.00E+00	0.36	0.35%	0.00%	0.36%

Table K.4(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1364 kN.

		P=1364 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	6.45E-04	0.0025	0	0.0025	0.03%	0.00%	0.02%
10%	2.58E-03	0.01	0	0.0025	0.05%	0.00%	0.02%
15%	5.81E-03	0.01	0	0.0225	0.05%	0.00%	0.07%
20%	1.03E-02	0.04	0	0.0225	0.11%	0.00%	0.07%
25%	1.61E-02	0.0625	0	0.04	0.13%	0.00%	0.10%
30%	2.32E-02	0.09	0	0.1225	0.16%	0.00%	0.17%
35%	3.16E-02	0.16	0	0.16	0.21%	0.00%	0.20%
40%	4.13E-02	0.25	0	0.3025	0.27%	0.00%	0.27%
45%	5.23E-02	5.5225	1.44	0.36	1.25%	0.62%	0.30%
50%	6.45E-02	260.8225	248.0625	238.7025	8.59%	8.11%	7.71%

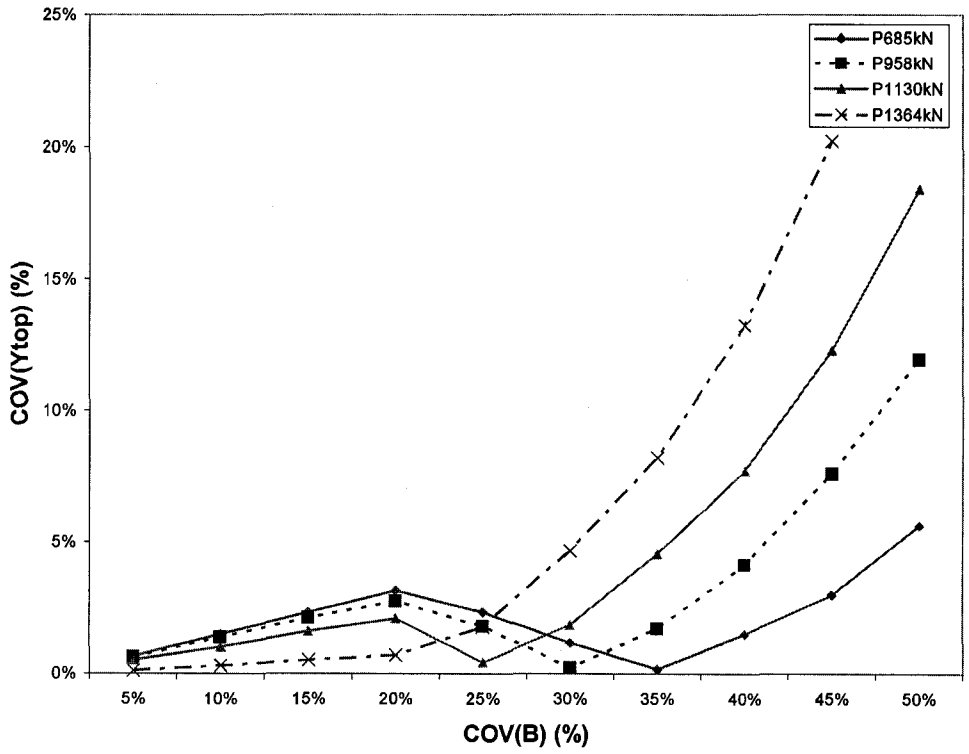

Fig. K.1 COV(Y_{Top}) for varying COV(B) in hinged head long (10T) pile group with spacing (5D).

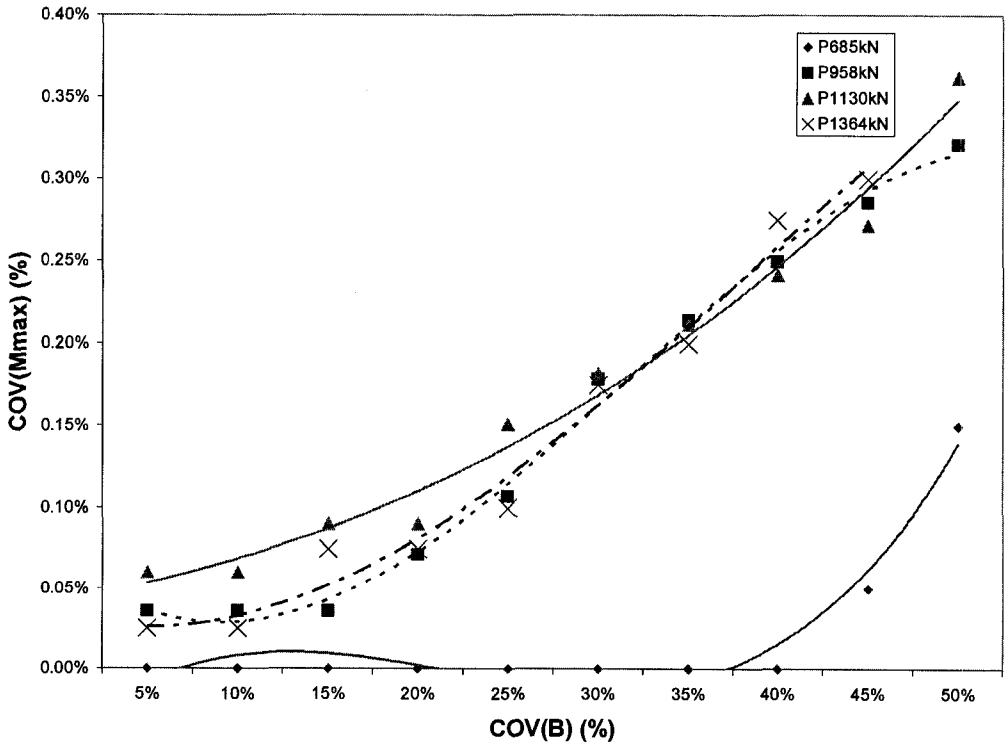

Fig. K.2(a) COV(M_{Max}) for varying COV(B) for pile C in hinged head long pile group with spacing (5D).

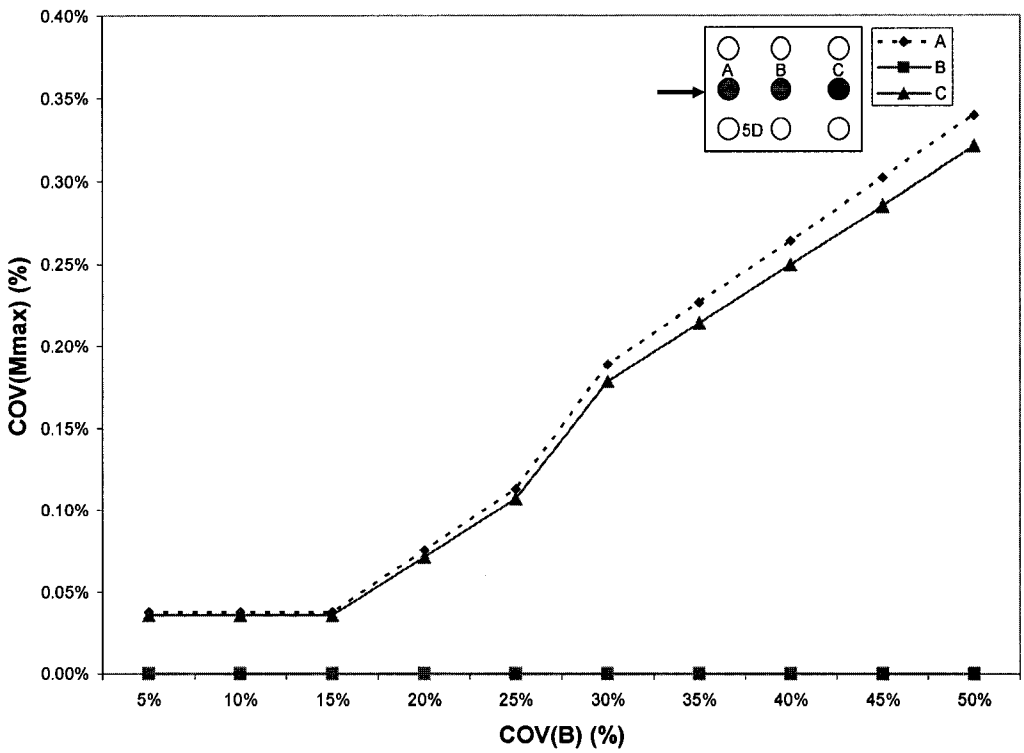

Fig. K.2(b) COV(M_{Max}) for varying COV(B) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (5D) at the optimum lateral load 958 kN.

K.1.2 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (5D) and with 'C' as varying random design variable

Table K.5. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 685 kN and 958 kN.

			P=685 kN (74, 76, 78 kN)				P=958 kN (100, 110, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	0.00511	94.29	97.53	100.7	0.00889	140	142.8	145.6
45.00%	1139.0625	41.25	0.00472	94.44	97.53	100.6	0.00804	133.7	136.4	141
40.00%	900	45	0.0044	94.49	97.53	100.6	0.00735	131.8	136.4	141
35.00%	689.0625	48.75	0.00413	94.54	97.53	100.5	0.0068	131.8	136.4	140.9
30.00%	506.25	52.5	0.0039	94.59	97.53	100.5	0.00633	132	136.4	140.8
25.00%	351.5625	56.25	0.0037	94.64	97.53	100.4	0.00594	132	136.4	140.7
20.00%	225	60	0.00352	94.68	97.53	100.4	0.00561	132.1	136.4	140.6
15.00%	126.5625	63.75	0.00337	94.8	97.53	100.3	0.00534	132.3	136.4	140.5
10.00%	56.25	67.5	0.00325	94.81	97.52	100.3	0.00511	132.4	136.4	140.4
5.00%	14.0625	71.25	0.00313	94.79	97.51	100.3	0.00491	132.4	136.4	140.4
0.00%	0	75	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
5.00%	14.0625	78.75	0.00292	94.77	97.51	100.3	0.00458	132.6	136.4	140.2
10.00%	56.25	82.5	0.00282	94.77	97.52	100.3	0.00444	132.6	136.4	140.3
15.00%	126.5625	86.25	0.00273	94.78	97.52	100.3	0.0043	132.5	136.4	140.3
20.00%	225	90	0.00265	94.8	97.51	100.3	0.00417	132.5	136.4	140.3
25.00%	351.5625	93.75	0.00257	94.8	97.51	100.3	0.00405	132.5	136.4	140.3
30.00%	506.25	97.5	0.0025	94.81	97.51	100.3	0.00394	132.5	136.4	140.3
35.00%	689.0625	101.25	0.00243	94.82	97.51	100.3	0.00383	132.5	136.4	140.3
40.00%	900	105	0.00237	94.84	97.51	100.3	0.00373	132.6	136.4	140.3
45.00%	1139.0625	108.75	0.00231	94.9	97.56	100.2	0.00364	132.6	136.4	140.3
50.00%	1406.25	112.5	0.0023	95.36	97.55	99.71	0.00356	132.6	136.4	140.3

Table K.6. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1130kN and 1364kN.

			P=1130 kN (120, 130, 130 kN)				P=1364 kN (150, 150, 160 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	0.012	177.4	180.9	184.4	0.0176	235.8	241.6	247
45.00%	1139.0625	41.25	0.0108	168.6	172	175.3	0.0154	223.7	228.2	232.8
40.00%	900	45	0.00976	161	164.2	167.2	0.0139	212.6	216.9	221.2
35.00%	689.0625	48.75	0.00897	155.4	160.9	166.3	0.0126	203.1	207.2	211.2
30.00%	506.25	52.5	0.0083	155.5	160.9	166.3	0.0116	194.7	198.4	202
25.00%	351.5625	56.25	0.00773	155.6	160.9	166.2	0.0107	187.5	194.2	200.8
20.00%	225	60	0.00726	155.6	160.9	166.1	0.00999	187.6	194.2	200.7
15.00%	126.5625	63.75	0.00687	155.6	160.9	166.1	0.00937	187.7	194.2	200.6
10.00%	56.25	67.5	0.00652	155.8	160.9	165.9	0.00884	187.8	194.2	200.5
5.00%	14.0625	71.25	0.00621	155.9	160.9	165.8	0.00838	187.9	194.2	200.5
0.00%	0	75	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5.00%	14.0625	78.75	0.00572	156.3	160.9	165.5	0.00762	188.1	194.2	200.3
10.00%	56.25	82.5	0.00554	156.4	160.8	165.4	0.0073	188.1	194.2	200.2
15.00%	126.5625	86.25	0.00538	156.4	160.9	165.4	0.00702	188.3	194.2	200.1
20.00%	225	90	0.00522	156.4	160.9	165.4	0.00679	188.6	194.2	199.8
25.00%	351.5625	93.75	0.00507	156.3	160.9	165.5	0.00657	188.6	194.2	199.8
30.00%	506.25	97.5	0.00493	156.3	160.9	165.5	0.00638	188.6	194.2	199.9
35.00%	689.0625	101.25	0.0048	156.3	160.9	165.5	0.00621	188.6	194.2	199.8
40.00%	900	105	0.00468	156.3	160.9	165.5	0.00605	188.7	194.2	199.7
45.00%	1139.0625	108.75	0.00456	156.3	160.9	165.5	0.0059	188.7	194.2	199.8
50.00%	1406.25	112.5	0.00445	156.4	160.9	165.5	0.00575	188.7	194.2	199.8

Table K.7(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 685 kN and 958 kN.

		P=685 kN		P=958 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	1.10E-08	3.477%	2.72E-08	3.481%
10.00%	5.63E+01	4.62E-08	7.119%	1.12E-07	7.068%
15.00%	1.27E+02	1.02E-07	10.596%	2.70E-07	10.970%
20.00%	2.25E+02	1.89E-07	14.404%	5.18E-07	15.190%
25.00%	3.52E+02	3.19E-07	18.709%	8.93E-07	19.937%
30.00%	5.06E+02	4.90E-07	23.179%	1.43E-06	25.211%
35.00%	6.89E+02	7.23E-07	28.146%	2.21E-06	31.329%
40.00%	9.00E+02	1.03E-06	33.609%	3.28E-06	38.186%
45.00%	1.14E+03	1.45E-06	39.901%	4.84E-06	46.414%
50.00%	1.41E+03	1.97E-06	46.523%	7.10E-06	56.224%

Table K.7(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1130 kN and 1364 kN.

		P=1130 kN		P=1364 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	1.41E+01	6.00E-08	4.118%	1.44E-07	4.768%
10.00%	5.63E+01	2.40E-07	8.235%	5.93E-07	9.661%
15.00%	1.27E+02	5.55E-07	12.521%	1.38E-06	14.743%
20.00%	2.25E+02	1.04E-06	17.143%	2.56E-06	20.075%
25.00%	3.52E+02	1.77E-06	22.353%	4.26E-06	25.910%
30.00%	5.06E+02	2.84E-06	28.319%	6.81E-06	32.748%
35.00%	6.89E+02	4.35E-06	35.042%	1.02E-05	40.088%
40.00%	9.00E+02	6.45E-06	42.689%	1.54E-05	49.247%
45.00%	1.14E+03	9.73E-06	52.437%	2.26E-05	59.598%
50.00%	1.41E+03	1.43E-05	63.445%	3.51E-05	74.341%

Table K.8(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 685 kN.

		P=685 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.0001	0	0	0.01%	0.00%	0.00%
10.00%	56.25	0.0004	0	0	0.02%	0.00%	0.00%
15.00%	126.5625	1E-04	2.5E-05	0	0.01%	0.01%	0.00%
20.00%	225	0.0036	1E-04	0.0025	0.06%	0.01%	0.05%
25.00%	351.5625	0.0064	1E-04	0.001	0.08%	0.01%	0.03%
30.00%	506.25	0.0121	1E-04	0.01	0.12%	0.01%	0.10%
35.00%	689.0625	0.0196	1E-04	0.01	0.15%	0.01%	0.10%
40.00%	900	0.030625	1E-04	0.0225	0.18%	0.01%	0.15%
45.00%	1139.0625	0.0529	0.000225	0.04	0.24%	0.02%	0.20%
50.00%	1406.25	0.286225	1E-04	0.245025	0.56%	0.01%	0.49%

Table K.8(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 958 kN.

		P=958 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.01	0	0.01	0.08%	0.00%	0.07%
10.00%	56.25	0.01	0	0.0025	0.08%	0.00%	0.04%
15.00%	126.5625	0.01	0	0.01	0.08%	0.00%	0.07%
20.00%	225	0.04	0	0.0225	0.15%	0.00%	0.11%
25.00%	351.5625	0.0625	0	0.04	0.19%	0.00%	0.14%
30.00%	506.25	0.0625	0	0.0625	0.19%	0.00%	0.18%
35.00%	689.0625	0.1225	0	0.09	0.26%	0.00%	0.21%
40.00%	900	0.16	0	0.1225	0.30%	0.00%	0.25%
45.00%	1139.0625	0.3025	0	0.1225	0.42%	0.00%	0.25%
50.00%	1406.25	13.69	10.24	7.0225	2.79%	2.35%	1.89%

Table K.8(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1130 kN.

		P=1130 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.04	0	0.0225	0.13%	0.00%	0.09%
10.00%	56.25	0.09	0.0025	0.0625	0.19%	0.03%	0.15%
15.00%	126.5625	0.16	0	0.1225	0.26%	0.00%	0.21%
20.00%	225	0.16	0	0.1225	0.26%	0.00%	0.21%
25.00%	351.5625	0.1225	0	0.1225	0.22%	0.00%	0.21%
30.00%	506.25	0.16	0	0.16	0.26%	0.00%	0.24%
35.00%	689.0625	0.2025	0	0.16	0.29%	0.00%	0.24%
40.00%	900	5.5225	2.7225	0.7225	1.51%	1.03%	0.51%
45.00%	1139.0625	37.8225	30.8025	24.01	3.94%	3.45%	2.96%
50.00%	1406.25	110.25	100	89.3025	6.73%	6.22%	5.70%

Table K.8(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1364 kN.

		P=1364 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	0.01	0	0.01	0.05%	0.00%	0.05%
10.00%	56.25	0.0225	0	0.0225	0.08%	0.00%	0.07%
15.00%	126.5625	0.09	0	0.0625	0.16%	0.00%	0.12%
20.00%	225	0.25	0	0.2025	0.27%	0.00%	0.22%
25.00%	351.5625	0.3025	0	0.25	0.29%	0.00%	0.25%
30.00%	506.25	9.3025	4.41	1.1025	1.62%	1.08%	0.52%
35.00%	689.0625	52.5625	42.25	32.49	3.86%	3.35%	2.84%
40.00%	900	142.8025	128.8225	115.5625	6.36%	5.84%	5.36%
45.00%	1139.0625	306.25	289	272.25	9.31%	8.75%	8.23%
50.00%	1406.25	554.6025	561.69	556.96	12.53%	12.20%	11.78%

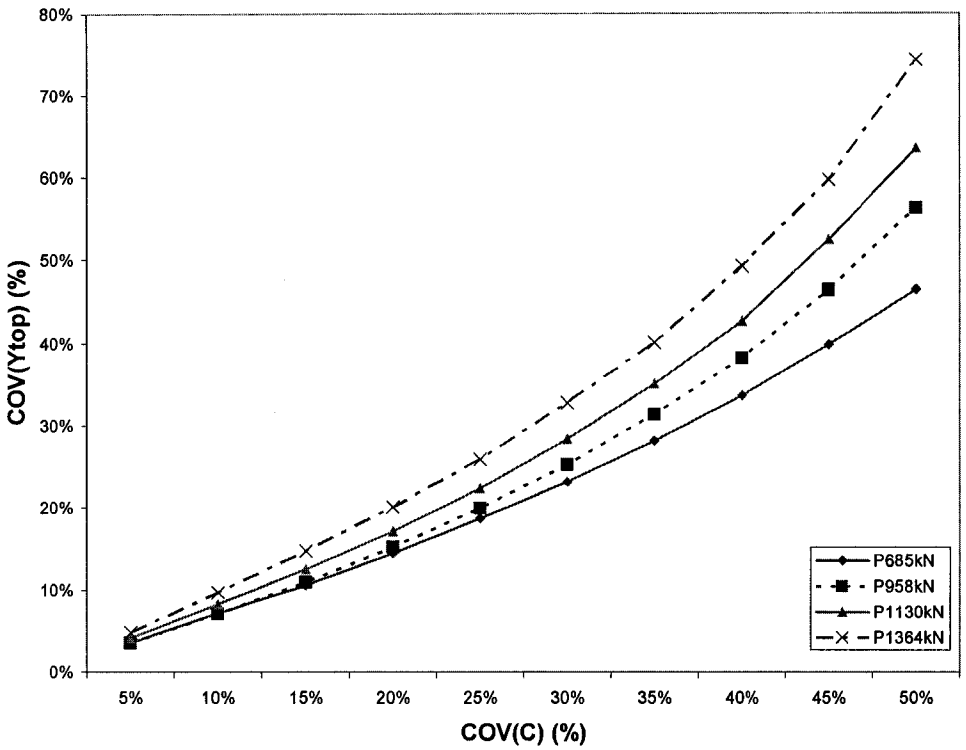

Fig. K.3 COV(Y_{Top}) for varying COV(C) in hinged head long (10T) pile group with spacing (5D).

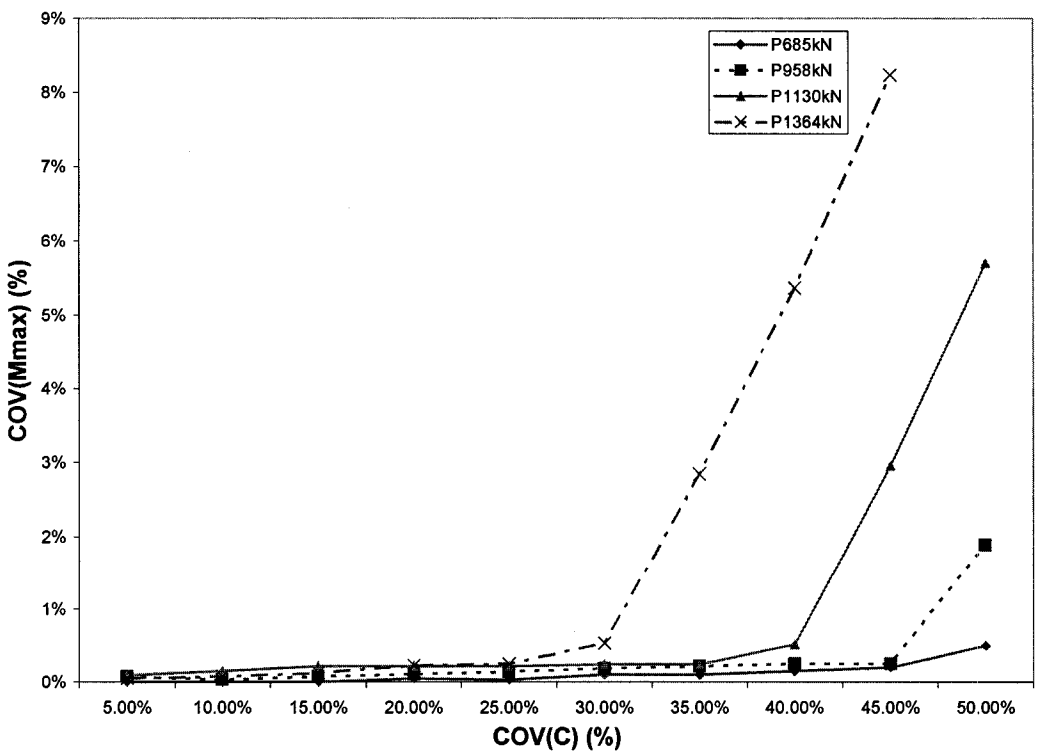

Fig. K.4(a) COV(M_{Max}) for varying COV(C) for pile C in hinged head long pile group with spacing (5D).

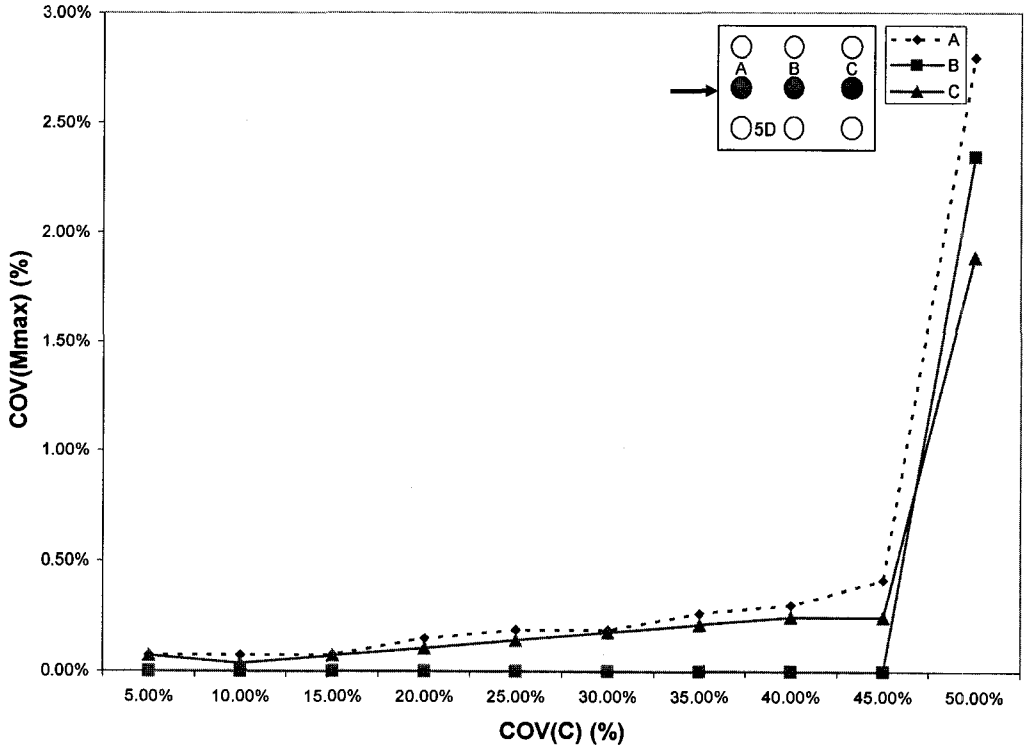

Fig. K.4(b) COV(M_{Max}) for varying COV(C) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (5D) at the optimum lateral load 958 kN.

K.1.3 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (5D) and with 'ε_{50}' as varying random design variable

Table K.9. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 685 kN and 958 kN.

			P=685 kN (74, 76, 78 kN)				P=958 kN (100, 110, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00235	94.85	97.51	100.3	0.00372	132.4	136.4	140.4
45%	9.9225E-06	0.00385	0.00243	94.82	97.51	100.3	0.00383	132.4	136.4	140.4
40%	0.00000784	0.0042	0.00251	94.81	97.51	100.3	0.00395	132.5	136.4	140.3
35%	6.0025E-06	0.00455	0.00258	94.8	97.51	100.3	0.00407	132.5	136.4	140.3
30%	0.00000441	0.0049	0.00265	94.79	97.51	100.3	0.00418	132.5	136.4	140.3
25%	3.0625E-06	0.00525	0.00271	94.78	97.52	100.3	0.00429	132.6	136.4	140.3
20%	0.00000196	0.0056	0.00278	94.76	97.51	100.3	0.00439	132.6	136.4	140.3
15%	1.1025E-06	0.00595	0.00285	94.77	97.51	100.3	0.00448	132.6	136.4	140.3
10%	0.00000049	0.0063	0.00291	94.77	97.51	100.3	0.00457	132.6	136.4	140.2
5%	1.225E-07	0.00665	0.00297	94.77	97.51	100.3	0.00466	132.6	136.4	140.2
0%	0	0.007	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
5%	1.225E-07	0.00735	0.00307	94.78	97.51	100.3	0.00482	132.4	136.4	140.2
10%	0.00000049	0.0077	0.00312	94.79	97.51	100.3	0.0049	132.4	136.4	140.3
15%	1.1025E-06	0.00805	0.00317	94.8	97.51	100.3	0.00498	132.4	136.4	140.4
20%	0.00000196	0.0084	0.00322	94.81	97.51	100.3	0.00506	132.4	136.4	140.4
25%	3.0625E-06	0.00875	0.00327	94.81	97.52	100.3	0.00514	132.4	136.4	140.4
30%	0.00000441	0.0091	0.00331	94.79	97.53	100.3	0.00522	132.3	136.4	140.5
35%	6.0025E-06	0.00945	0.00336	94.77	97.52	100.3	0.0053	132.3	136.4	140.5
40%	0.00000784	0.0098	0.00339	94.79	97.53	100.3	0.00538	132.3	136.4	140.5
45%	9.9225E-06	0.01015	0.00343	94.74	97.55	100.3	0.00545	132.3	136.4	140.5
50%	0.00001225	0.0105	0.00347	94.71	97.54	100.3	0.00552	132.3	136.4	140.5

Table K.10. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1130 kN and 1364 kN.

			P=1130 kN (120, 130, 130 kN)				P=1364 kN (150, 150, 160 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.0048	156	160.9	165.8	0.00653	188.3	194.2	200.1
45%	9.9225E-06	0.00385	0.00493	156	160.9	165.8	0.00668	188.4	194.2	200
40%	0.00000784	0.0042	0.00507	156.1	160.9	165.7	0.00682	188.5	194.2	200
35%	6.0025E-06	0.00455	0.00519	156.1	160.9	165.7	0.00697	188.4	194.3	199.9
30%	0.00000441	0.0049	0.00531	156.2	160.9	165.6	0.00711	188.2	194.2	200.2
25%	3.0625E-06	0.00525	0.00542	156.2	160.9	165.6	0.00726	188.1	194.2	200.3
20%	0.00000196	0.0056	0.00553	156.3	160.9	165.5	0.00741	188.1	194.2	200.3
15%	1.1025E-06	0.00595	0.00563	156.2	160.9	165.5	0.00757	188.1	194.2	200.3
10%	0.00000049	0.0063	0.00574	156.1	160.9	165.7	0.0077	188.1	194.2	200.3
5%	1.225E-07	0.00665	0.00584	156	160.9	165.7	0.00784	188	194.2	200.3
0%	0	0.007	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5%	1.225E-07	0.00735	0.00605	156	160.9	165.7	0.0081	188	194.2	200.4
10%	0.00000049	0.0077	0.00616	156.1	160.9	165.7	0.00823	188	194.2	200.4
15%	1.1025E-06	0.00805	0.00626	156.1	160.9	165.7	0.00836	188	194.2	200.4
20%	0.00000196	0.0084	0.00636	156.1	160.9	165.7	0.00848	187.9	194.2	200.4
25%	3.0625E-06	0.00875	0.00647	156	160.9	165.7	0.0086	187.9	194.2	200.4
30%	0.00000441	0.0091	0.00656	156	160.9	165.7	0.00872	187.9	194.2	200.5
35%	6.0025E-06	0.00945	0.00666	156	160.9	165.8	0.00884	187.9	194.2	200.5
40%	0.00000784	0.0098	0.00676	156	160.9	165.8	0.00898	187.9	194.2	200.5
45%	9.9225E-06	0.01015	0.00685	156	160.9	165.8	0.00909	187.9	194.2	200.5
50%	0.00001225	0.0105	0.00696	155.9	160.9	165.8	0.0092	187.9	194.2	200.5

Table K.11(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 685 kN and 958 kN.

		P=685 kN		P=958 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	2.50E-09	1.656%	6.40E-09	1.688%
10%	4.90E-07	1.10E-08	3.477%	2.72E-08	3.481%
15%	1.10E-06	2.56E-08	5.298%	6.25E-08	5.274%
20%	1.96E-06	4.84E-08	7.285%	1.12E-07	7.068%
25%	3.06E-06	7.84E-08	9.272%	1.81E-07	8.966%
30%	4.41E-06	1.09E-07	10.927%	2.70E-07	10.970%
35%	6.00E-06	1.52E-07	12.914%	3.78E-07	12.975%
40%	7.84E-06	1.94E-07	14.570%	5.11E-07	15.084%
45%	9.92E-06	2.50E-07	16.556%	6.56E-07	17.089%
50%	1.23E-05	3.14E-07	18.543%	8.10E-07	18.987%

Table K.11(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1130 kN and 1364 kN.

		P=1130 kN		P=1364 kN	
$COV(\varepsilon_{50})$ (%)	Var (ε_{50})	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	1.23E-07	1.10E-08	1.765%	1.69E-08	1.631%
10%	4.90E-07	4.41E-08	3.529%	7.02E-08	3.325%
15%	1.10E-06	9.92E-08	5.294%	1.56E-07	4.956%
20%	1.96E-06	1.72E-07	6.975%	2.86E-07	6.713%
25%	3.06E-06	2.76E-07	8.824%	4.49E-07	8.407%
30%	4.41E-06	3.91E-07	10.504%	6.48E-07	10.100%
35%	6.00E-06	5.40E-07	12.353%	8.74E-07	11.731%
40%	7.84E-06	7.14E-07	14.202%	1.17E-06	13.551%
45%	9.92E-06	9.22E-07	16.134%	1.45E-06	15.119%
50%	1.23E-05	1.17E-06	18.151%	1.78E-06	16.750%

Table K.12(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 685 kN.

		P=685 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	2.50E-05	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
10%	4.90E-07	1.00E-04	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
15%	1.10E-06	2.25E-04	0.00E+00	0.00E+00	0.02%	0.00%	0.00%
20%	1.96E-06	6.25E-04	0.00E+00	0.00E+00	0.03%	0.00%	0.00%
25%	3.06E-06	2.25E-04	0.00E+00	0.00E+00	0.02%	0.00%	0.00%
30%	4.41E-06	0.00E+00	1.00E-04	0.00E+00	0.00%	0.01%	0.00%
35%	6.00E-06	2.25E-04	2.50E-05	0.00E+00	0.02%	0.01%	0.00%
40%	7.84E-06	1.00E-04	1.00E-04	0.00E+00	0.01%	0.01%	0.00%
45%	9.92E-06	1.60E-03	4.00E-04	0.00E+00	0.04%	0.02%	0.00%
50%	1.23E-05	4.90E-03	2.25E-04	0.00E+00	0.07%	0.02%	0.00%

Table K.12(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 958 kN.

		P=958 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.01	0.00E+00	0	0.08%	0.00%	0.00%
10%	4.90E-07	0.01	0.00E+00	0.0025	0.08%	0.00%	0.04%
15%	1.10E-06	0.01	0.00E+00	0.0025	0.08%	0.00%	0.04%
20%	1.96E-06	0.01	0.00E+00	0.0025	0.08%	0.00%	0.04%
25%	3.06E-06	0.01	0.00E+00	0.0025	0.08%	0.00%	0.04%
30%	4.41E-06	0.01	0.00E+00	0.01	0.08%	0.00%	0.07%
35%	6.00E-06	0.01	0.00E+00	0.01	0.08%	0.00%	0.07%
40%	7.84E-06	0.01	0.00E+00	0.01	0.08%	0.00%	0.07%
45%	9.92E-06	0.0025	0.00E+00	0.0025	0.04%	0.00%	0.04%
50%	1.23E-05	0.0025	0.00E+00	0.0025	0.04%	0.00%	0.04%

Table K.12(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1130 kN.

		P=1130 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0	0.00E+00	0	0.00%	0.00%	0.00%
10%	4.90E-07	0	0.00E+00	0	0.00%	0.00%	0.00%
15%	1.10E-06	0.0025	0.00E+00	0.01	0.03%	0.00%	0.06%
20%	1.96E-06	0.01	0.00E+00	0.01	0.06%	0.00%	0.06%
25%	3.06E-06	0.01	0.00E+00	0.0025	0.06%	0.00%	0.03%
30%	4.41E-06	0.01	0.00E+00	0.0025	0.06%	0.00%	0.03%
35%	6.00E-06	0.0025	0.00E+00	0.0025	0.03%	0.00%	0.03%
40%	7.84E-06	0.0025	0.00E+00	0.0025	0.03%	0.00%	0.03%
45%	9.92E-06	0	0.00E+00	0	0.00%	0.00%	0.00%
50%	1.23E-05	0.0025	0.00E+00	0	0.03%	0.00%	0.00%

Table K.12(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1364 kN.

		P=1364 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0	0	0.0025	0.00%	0.00%	0.02%
10%	4.90E-07	0.0025	0	0.0025	0.03%	0.00%	0.02%
15%	1.10E-06	0.0025	0	0.0025	0.03%	0.00%	0.02%
20%	1.96E-06	0.01	0	0.0025	0.05%	0.00%	0.02%
25%	3.06E-06	0.01	0	0.0025	0.05%	0.00%	0.02%
30%	4.41E-06	0.0225	0	0.0225	0.08%	0.00%	0.07%
35%	6.00E-06	0.0625	0.0025	0.09	0.13%	0.03%	0.15%
40%	7.84E-06	0.09	0	0.0625	0.16%	0.00%	0.12%
45%	9.92E-06	0.0625	0	0.0625	0.13%	0.00%	0.12%
50%	1.23E-05	0.04	0	0.04	0.11%	0.00%	0.10%

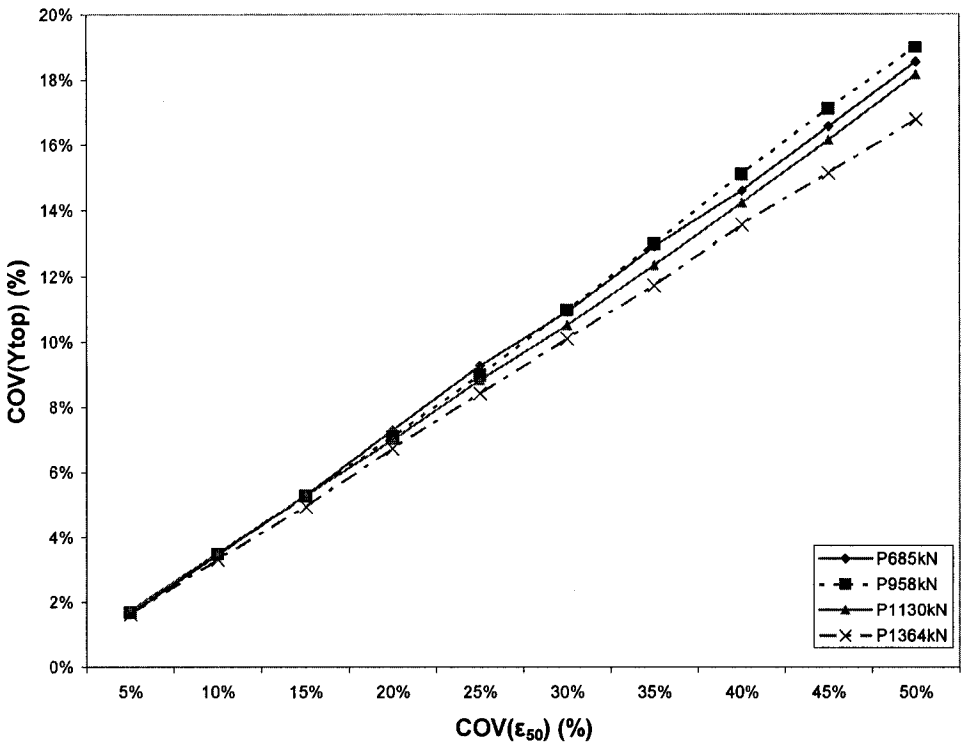

Fig. K.5 COV(Y_{Top}) for varying COV(ε_{50}) in hinged head long (10T) pile group with spacing (5D).

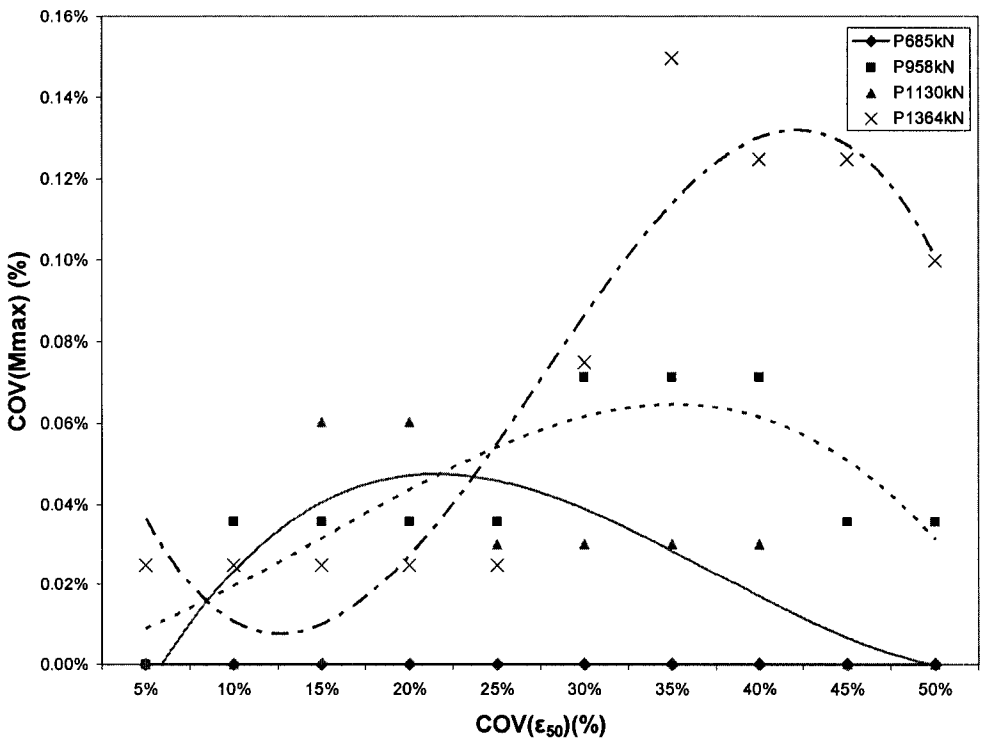

Fig. K.6(a) COV(M_{Max}) for varying COV(ε_{50}) for pile C in hinged head long pile group with spacing (5D).

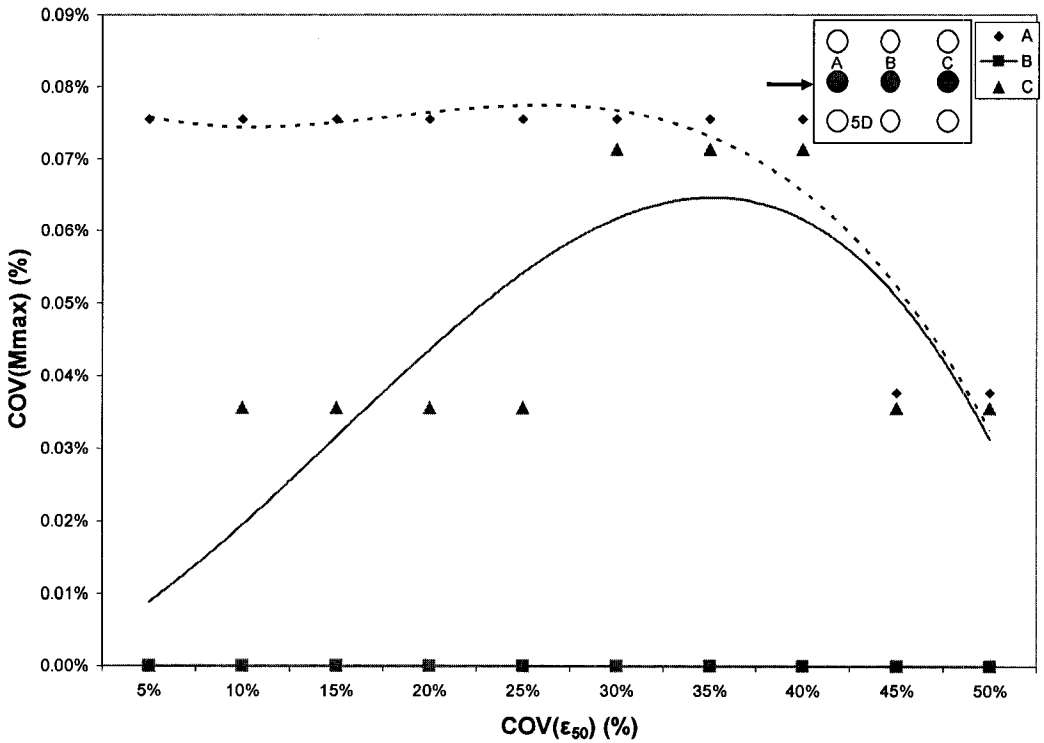

Fig. K.6(b) COV(M_{Max}) for varying COV(ε_{50}) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (5D) at the optimum lateral load 958 kN.

K.1.4 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (5D) and with 'EI' as varying random design variable

Table K.13. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 685 kN and 958 kN.

			P=685 kN (74, 76, 78 kN)				P=958 kN (100, 110, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00464	94.76	97.53	100.3	0.00734	132.3	136.4	140.4
45%	2.45E+09	60500	0.00437	94.76	97.52	100.3	0.00691	132.4	136.4	140.4
40%	1.94E+09	66000	0.00414	94.75	97.52	100.3	0.00653	132.4	136.4	140.3
35%	1.48E+09	71500	0.00395	94.76	97.52	100.3	0.00622	132.4	136.4	140.3
30%	1.09E+09	77000	0.00377	94.76	97.52	100.3	0.00593	132.4	136.4	140.2
25%	7.56E+08	82500	0.00361	94.76	97.52	100.3	0.00568	132.4	136.4	140.2
20%	4.84E+08	88000	0.00347	94.76	97.52	100.3	0.00545	132.4	136.4	140.2
15%	2.72E+08	93500	0.00334	94.77	97.52	100.3	0.00525	132.4	136.4	140.2
10%	1.21E+08	99000	0.00322	94.77	97.51	100.3	0.00506	132.4	136.4	140.2
5%	3.03E+07	104500	0.00312	94.78	97.51	100.3	0.0049	132.4	136.4	140.2
0%	0.00E+00	110000	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
5%	3.03E+07	115500	0.00293	94.78	97.51	100.3	0.00459	132.4	136.4	140.2
10%	1.21E+08	121000	0.00285	94.79	97.51	100.3	0.00446	132.4	136.4	140.2
15%	2.72E+08	126500	0.00277	94.79	97.51	100.3	0.00434	132.4	136.4	140.3
20%	4.84E+08	132000	0.0027	94.79	97.51	100.3	0.00423	132.4	136.4	140.3
25%	7.56E+08	137500	0.00263	94.79	97.51	100.3	0.00412	132.4	136.4	140.4
30%	1.09E+09	143000	0.00257	94.8	97.51	100.3	0.00403	132.4	136.4	140.4
35%	1.48E+09	148500	0.00251	94.81	97.51	100.3	0.00394	132.4	136.4	140.4
40%	1.94E+09	154000	0.00245	94.81	97.51	100.3	0.00385	132.4	136.4	140.5
45%	2.45E+09	159500	0.0024	94.82	97.51	100.3	0.00377	132.4	136.4	140.5
50%	3.03E+09	165000	0.00235	94.82	97.51	100.3	0.00369	132.4	136.4	140.5

Table K.14. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1130 kN and 1364 kN.

			P=1130 kN (120, 130, 130 kN)				P=1364 kN (150, 150, 160 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00946	156.1	160.9	165.6	0.0128	188.2	194.2	200.2
45%	2.45E+09	60500	0.00886	156.1	160.9	165.6	0.0119	188.1	194.2	200.2
40%	1.94E+09	66000	0.00835	156.2	160.9	165.6	0.0112	188.1	194.2	200.2
35%	1.48E+09	71500	0.00791	156.1	160.9	165.6	0.0107	188.1	194.2	200.2
30%	1.09E+09	77000	0.00751	156.2	160.9	165.6	0.0101	188.1	194.2	200.3
25%	7.56E+08	82500	0.00717	156.1	160.9	165.6	0.00966	188.1	194.2	200.3
20%	4.84E+08	88000	0.00687	156.1	160.9	165.7	0.00924	188.1	194.2	200.3
15%	2.72E+08	93500	0.0066	156	160.9	165.7	0.00888	188	194.2	200.3
10%	1.21E+08	99000	0.00636	156	160.9	165.7	0.00854	188	194.2	200.3
5%	3.03E+07	104500	0.00615	156	160.9	165.7	0.00825	188	194.2	200.3
0%	0.00E+00	110000	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5%	3.03E+07	115500	0.00577	156	160.9	165.7	0.00772	188	194.2	200.4
10%	1.21E+08	121000	0.0056	156	160.9	165.7	0.00749	188	194.2	200.5
15%	2.72E+08	126500	0.00545	156	160.9	165.7	0.00728	188	194.2	200.5
20%	4.84E+08	132000	0.00532	156	160.9	165.7	0.00708	187.9	194.2	200.5
25%	7.56E+08	137500	0.00519	156	160.9	165.7	0.0069	187.9	194.2	200.5
30%	1.09E+09	143000	0.00507	156	160.9	165.7	0.00673	187.9	194.2	200.5
35%	1.48E+09	148500	0.00495	156	160.9	165.7	0.00657	187.9	194.2	200.5
40%	1.94E+09	154000	0.00485	156	160.9	165.8	0.00642	187.9	194.2	200.5
45%	2.45E+09	159500	0.00475	156	160.9	165.8	0.00628	187.9	194.2	200.5
50%	3.03E+09	165000	0.00465	156	160.9	165.8	0.00616	187.9	194.2	200.5

Table K.15(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 685 kN and 958 kN.

		P=685 kN		P=958 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	9.03E-09	3.146%	2.40E-08	3.270%
10%	1.21E+08	3.42E-08	6.126%	9.00E-08	6.329%
15%	2.72E+08	8.12E-08	9.437%	2.07E-07	9.599%
20%	4.84E+08	1.48E-07	12.748%	3.72E-07	12.869%
25%	7.56E+08	2.40E-07	16.225%	6.08E-07	16.456%
30%	1.09E+09	3.60E-07	19.868%	9.03E-07	20.042%
35%	1.48E+09	5.18E-07	23.841%	1.30E-06	24.051%
40%	1.94E+09	7.14E-07	27.980%	1.80E-06	28.270%
45%	2.45E+09	9.70E-07	32.616%	2.46E-06	33.122%
50%	3.03E+09	1.31E-06	37.914%	3.33E-06	38.502%

Table K.15(b) Value of COV(Y_{Top}) for hinged head long pile (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1130 kN and 1364 kN.

		P=1130 kN		P=1364 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	3.03E+07	3.61E-08	3.193%	7.02E-08	3.325%
10%	1.21E+08	1.44E-07	6.387%	2.76E-07	6.587%
15%	2.72E+08	3.31E-07	9.664%	6.40E-07	10.038%
20%	4.84E+08	6.01E-07	13.025%	1.17E-06	13.551%
25%	7.56E+08	9.80E-07	16.639%	1.90E-06	17.315%
30%	1.09E+09	1.49E-06	20.504%	2.84E-06	21.142%
35%	1.48E+09	2.19E-06	24.874%	4.26E-06	25.910%
40%	1.94E+09	3.06E-06	29.412%	5.71E-06	29.987%
45%	2.45E+09	4.22E-06	34.538%	7.90E-06	35.257%
50%	3.03E+09	5.78E-06	40.420%	1.10E-05	41.656%

Table K.16(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 685 kN.

		P=685 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	1.21E+08	0.0001	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
15%	2.72E+08	0.0001	2.50E-05	0.00E+00	0.01%	0.01%	0.00%
20%	4.84E+08	0.000225	2.50E-05	0.00E+00	0.02%	0.01%	0.00%
25%	7.56E+08	0.000225	2.50E-05	0.00E+00	0.02%	0.01%	0.00%
30%	1.09E+09	0.0004	2.50E-05	0.00E+00	0.02%	0.01%	0.00%
35%	1.48E+09	0.000625	2.50E-05	0.00E+00	0.03%	0.01%	0.00%
40%	1.94E+09	0.0009	2.50E-05	0.00E+00	0.03%	0.01%	0.00%
45%	2.45E+09	0.0009	2.50E-05	0.00E+00	0.03%	0.01%	0.00%
50%	3.03E+09	0.0009	1.00E-04	0.00E+00	0.03%	0.01%	0.00%

Table K.16(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 958 kN.

		P=958 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.00E+00	0.00E+00	0	0.00%	0.00%	0.00%
10%	1.21E+08	0.00E+00	0.00E+00	0	0.00%	0.00%	0.00%
15%	2.72E+08	0.00E+00	0.00E+00	0.0025	0.00%	0.00%	0.04%
20%	4.84E+08	0.00E+00	0.00E+00	0.0025	0.00%	0.00%	0.04%
25%	7.56E+08	0.00E+00	0.00E+00	0.01	0.00%	0.00%	0.07%
30%	1.09E+09	0.00E+00	0.00E+00	0.01	0.00%	0.00%	0.07%
35%	1.48E+09	0.00E+00	0.00E+00	0.0025	0.00%	0.00%	0.04%
40%	1.94E+09	0.00E+00	0.00E+00	0.01	0.00%	0.00%	0.07%
45%	2.45E+09	0.00E+00	0.00E+00	0.0025	0.00%	0.00%	0.04%
50%	3.03E+09	2.50E-03	0.00E+00	0.0025	0.04%	0.00%	0.04%

Table K.16(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1130 kN.

		P=1130 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0	0.00E+00	0	0.00%	0.00%	0.00%
10%	1.21E+08	0	0.00E+00	0	0.00%	0.00%	0.00%
15%	2.72E+08	0	0.00E+00	0	0.00%	0.00%	0.00%
20%	4.84E+08	0.0025	0.00E+00	0	0.03%	0.00%	0.00%
25%	7.56E+08	0.0025	0.00E+00	0.0025	0.03%	0.00%	0.03%
30%	1.09E+09	0.01	0.00E+00	0.0025	0.06%	0.00%	0.03%
35%	1.48E+09	0.0025	0.00E+00	0.0025	0.03%	0.00%	0.03%
40%	1.94E+09	0.01	0.00E+00	0.01	0.06%	0.00%	0.06%
45%	2.45E+09	0.0025	0.00E+00	0.01	0.03%	0.00%	0.06%
50%	3.03E+09	0.0025	0.00E+00	0.01	0.03%	0.00%	0.06%

Table K.16(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1364 kN.

		P=1364 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0	0.00E+00	0.0025	0.00%	0.00%	0.02%
10%	1.21E+08	0	0.00E+00	0.01	0.00%	0.00%	0.05%
15%	2.72E+08	0	0.00E+00	0.01	0.00%	0.00%	0.05%
20%	4.84E+08	0.01	0.00E+00	0.01	0.05%	0.00%	0.05%
25%	7.56E+08	0.01	0.00E+00	0.01	0.05%	0.00%	0.05%
30%	1.09E+09	0.01	0.00E+00	0.01	0.05%	0.00%	0.05%
35%	1.48E+09	0.01	0.00E+00	0.0225	0.05%	0.00%	0.07%
40%	1.94E+09	0.01	0.00E+00	0.0225	0.05%	0.00%	0.07%
45%	2.45E+09	0.01	0.00E+00	0.0225	0.05%	0.00%	0.07%
50%	3.03E+09	0.0225	0.00E+00	0.0225	0.08%	0.00%	0.07%

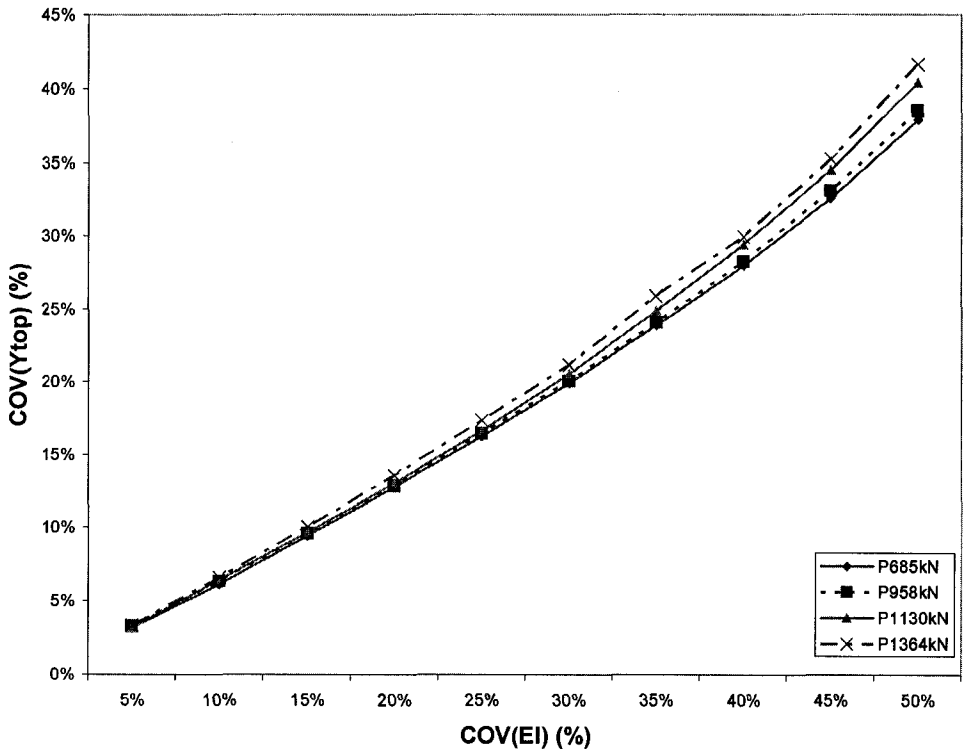

Fig. K.7 COV(Y_{Top}) for varying COV(EI) in hinged head long (10T) pile group with spacing (5D).

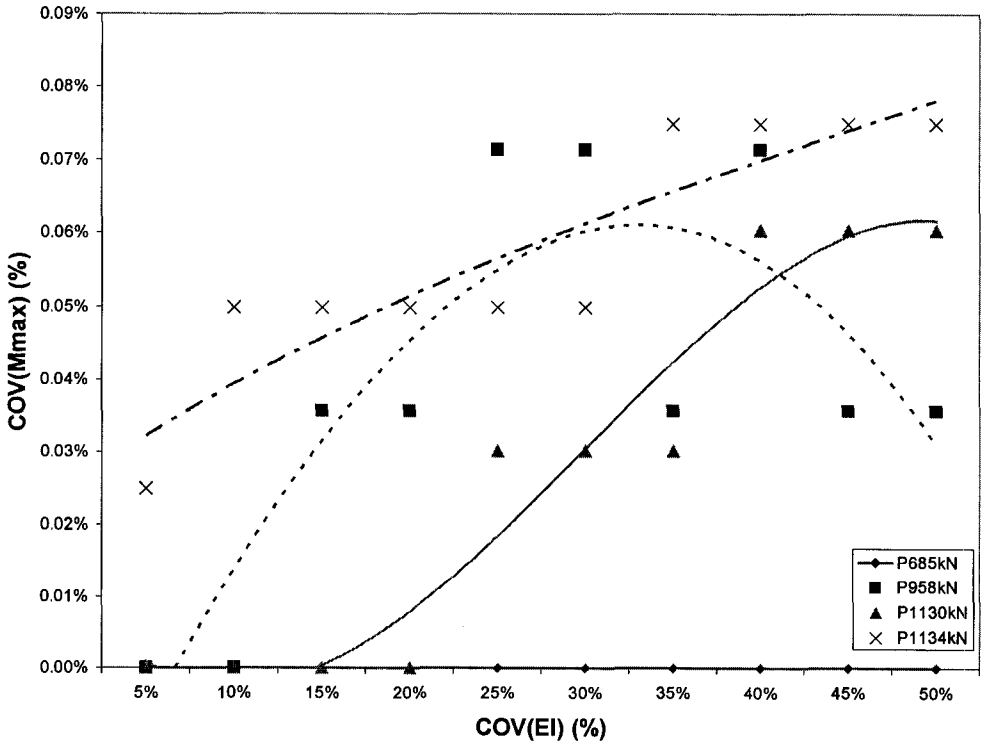

Fig. K.8(a) COV(M_{Max}) for varying COV(EI) for pile C in hinged head long pile group with spacing (5D).

Note: Value of COV(M_{MAX}) is zero for pile rows A, B, C with varying COV(EI) at optimum load 958 kN in hinged head long (10T) pile group with spacing (5D).

K.1.5 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (5D) and with 'k' as varying random design variable

Table K.17. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 685 kN and 958 kN.

			P=685 kN (74, 76, 78 kN)				P=958 kN (100, 110, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00315	95.16	97.51	99.95	0.00482	132.4	136.4	140.4
45%	3.75E+09	74800	0.00305	94.68	97.52	100.4	0.0048	132.4	136.4	140.4
40%	2.96E+09	81600	0.00305	94.7	97.52	100.4	0.00479	132.4	136.4	140.4
35%	2.27E+09	88400	0.00304	94.71	97.52	100.4	0.00478	132.4	136.4	140.3
30%	1.66E+09	95200	0.00303	94.73	97.52	100.4	0.00477	132.4	136.4	140.3
25%	1.16E+09	102000	0.00303	94.74	97.52	100.3	0.00476	132.4	136.4	140.3
20%	7.40E+08	108800	0.00303	94.74	97.51	100.3	0.00476	132.4	136.4	140.3
15%	4.16E+08	115600	0.00302	94.75	97.51	100.3	0.00475	132.4	136.4	140.2
10%	1.85E+08	122400	0.00302	94.76	97.51	100.3	0.00475	132.4	136.4	140.2
5%	4.62E+07	129200	0.00302	94.77	97.51	100.3	0.00474	132.4	136.4	140.2
0%	0.00E+00	136000	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
5%	4.62E+07	142800	0.00302	94.79	97.51	100.3	0.00473	132.6	136.4	140.2
10%	1.85E+08	149600	0.00302	94.79	97.51	100.3	0.00473	132.5	136.4	140.2
15%	4.16E+08	156400	0.00302	94.8	97.51	100.3	0.00473	132.5	136.4	140.3
20%	7.40E+08	163200	0.00302	94.81	97.51	100.3	0.00473	132.5	136.4	140.3
25%	1.16E+09	170000	0.00301	94.82	97.51	100.3	0.00473	132.5	136.4	140.3
30%	1.66E+09	176800	0.00301	94.82	97.51	100.3	0.00473	132.5	136.4	140.3
35%	2.27E+09	183600	0.00301	94.83	97.51	100.3	0.00473	132.5	136.4	140.3
40%	2.96E+09	190400	0.00301	94.83	97.51	100.3	0.00473	132.5	136.4	140.3
45%	3.75E+09	197200	0.00301	94.83	97.51	100.2	0.00473	132.5	136.4	140.3
50%	4.62E+09	204000	0.00301	94.83	97.52	100.2	0.00473	132.5	136.4	140.3

Table K.18. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1130 kN and 1364 kN.

			P=1130 kN (120, 130, 130 kN)				P=1364 kN (150, 150, 160 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00605	156	160.9	165.7	0.00803	188.4	194.2	200
45%	3.75E+09	74800	0.00603	156	160.9	165.7	0.00798	188.2	194.2	200.1
40%	2.96E+09	81600	0.00601	156	160.9	165.7	0.00796	188	194.2	200.3
35%	2.27E+09	88400	0.006	156	160.9	165.7	0.00797	188	194.2	200.4
30%	1.66E+09	95200	0.00597	156	160.9	165.7	0.00797	188	194.2	200.4
25%	1.16E+09	102000	0.00596	156	160.9	165.7	0.00797	188	194.2	200.4
20%	7.40E+08	108800	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
15%	4.16E+08	115600	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
10%	1.85E+08	122400	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5%	4.62E+07	129200	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
0%	0.00E+00	136000	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5%	4.62E+07	142800	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
10%	1.85E+08	149600	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
15%	4.16E+08	156400	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
20%	7.40E+08	163200	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
25%	1.16E+09	170000	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
30%	1.66E+09	176800	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
35%	2.27E+09	183600	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
40%	2.96E+09	190400	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
45%	3.75E+09	197200	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
50%	4.62E+09	204000	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4

Table K.19(a) Value of $COV(Y_{Top})$ for hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 685 kN and 958 kN.

		P=685 kN		P=958 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	4.62E+07	0.00E+00	0.000%	2.50E-11	0.105%
10%	1.85E+08	0.00E+00	0.000%	1.00E-10	0.211%
15%	4.16E+08	0.00E+00	0.000%	1.00E-10	0.211%
20%	7.40E+08	2.50E-11	0.166%	2.25E-10	0.316%
25%	1.16E+09	1.00E-10	0.331%	2.25E-10	0.316%
30%	1.66E+09	1.00E-10	0.331%	4.00E-10	0.422%
35%	2.27E+09	2.25E-10	0.497%	6.25E-10	0.527%
40%	2.96E+09	4.00E-10	0.662%	9.00E-10	0.633%
45%	3.75E+09	4.00E-10	0.662%	1.22E-09	0.738%
50%	4.62E+09	4.90E-09	2.318%	2.02E-09	0.949%

Table K.19(b) Value of $COV(Y_{Top})$ for hinged head long pile (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1130 kN and 1364 kN.

		P=1130 kN		P=1364 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	0.00E+00	0.000%
20%	7.40E+08	0.00E+00	0.000%	0.00E+00	0.000%
25%	1.16E+09	2.50E-11	0.084%	0.00E+00	0.000%
30%	1.66E+09	1.00E-10	0.168%	0.00E+00	0.000%
35%	2.27E+09	6.25E-10	0.420%	0.00E+00	0.000%
40%	2.96E+09	9.00E-10	0.504%	2.50E-11	0.063%
45%	3.75E+09	1.60E-09	0.672%	2.50E-11	0.063%
50%	4.62E+09	2.50E-09	0.840%	9.00E-10	0.376%

Table K.20(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 685 kN.

		P=685 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	1.00E-04	0.00E+00	0.00E+00	0.01%	0.00%	0.00%
10%	1.85E+08	2.25E-04	0.00E+00	0.00E+00	0.02%	0.00%	0.00%
15%	4.16E+08	6.25E-04	0.00E+00	0.00E+00	0.03%	0.00%	0.00%
20%	7.40E+08	1.23E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
25%	1.16E+09	1.60E-03	2.50E-05	0.00E+00	0.04%	0.01%	0.00%
30%	1.66E+09	2.02E-03	2.50E-05	2.50E-03	0.05%	0.01%	0.05%
35%	2.27E+09	3.60E-03	2.50E-05	2.50E-03	0.06%	0.01%	0.05%
40%	2.96E+09	4.22E-03	2.50E-05	2.50E-03	0.07%	0.01%	0.05%
45%	3.75E+09	5.62E-03	2.50E-05	1.00E-02	0.08%	0.01%	0.10%
50%	4.62E+09	2.72E-02	2.50E-05	1.56E-02	0.17%	0.01%	0.12%

Table K.20(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 958 kN.

		P=958 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	1.00E-02	0.00E+00	0.00E+00	0.08%	0.00%	0.00%
10%	1.85E+08	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
15%	4.16E+08	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%
20%	7.40E+08	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
25%	1.16E+09	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
30%	1.66E+09	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
35%	2.27E+09	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
40%	2.96E+09	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%
45%	3.75E+09	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%
50%	4.62E+09	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%

Table K.20(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1130 kN.

		P=1130 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	1.85E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	4.16E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	7.40E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	1.16E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	1.66E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	2.27E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	2.96E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	3.75E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
50%	4.62E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%

Table K.20(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1364 kN.

		P=1364 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	1.85E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	4.16E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	7.40E+08	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	1.16E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	1.66E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	2.27E+09	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	2.96E+09	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.02%
45%	3.75E+09	1.00E-02	0.00E+00	2.25E-02	0.05%	0.00%	0.07%
50%	4.62E+09	4.00E-02	0.00E+00	4.00E-02	0.11%	0.00%	0.10%

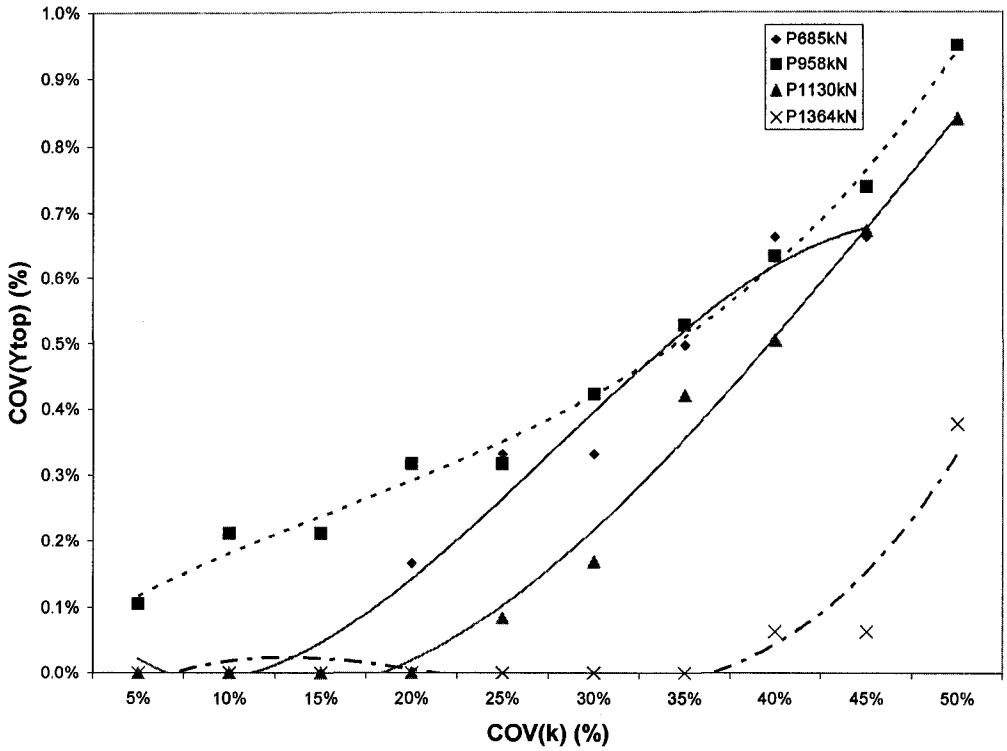

Fig. K.9 COV(Y_{Top}) for varying COV(k) in hinged head long (10T) pile group with spacing (5D).

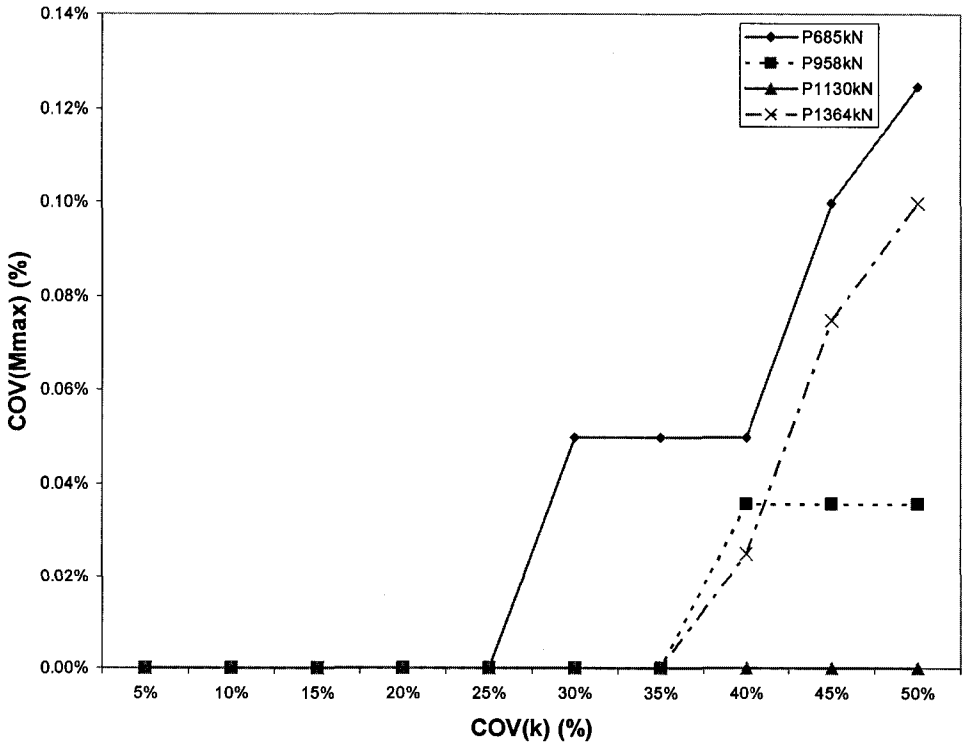

Fig. K.10(a) COV(M_{Max}) for varying COV(k) for pile C in hinged head long pile group with spacing (5D).

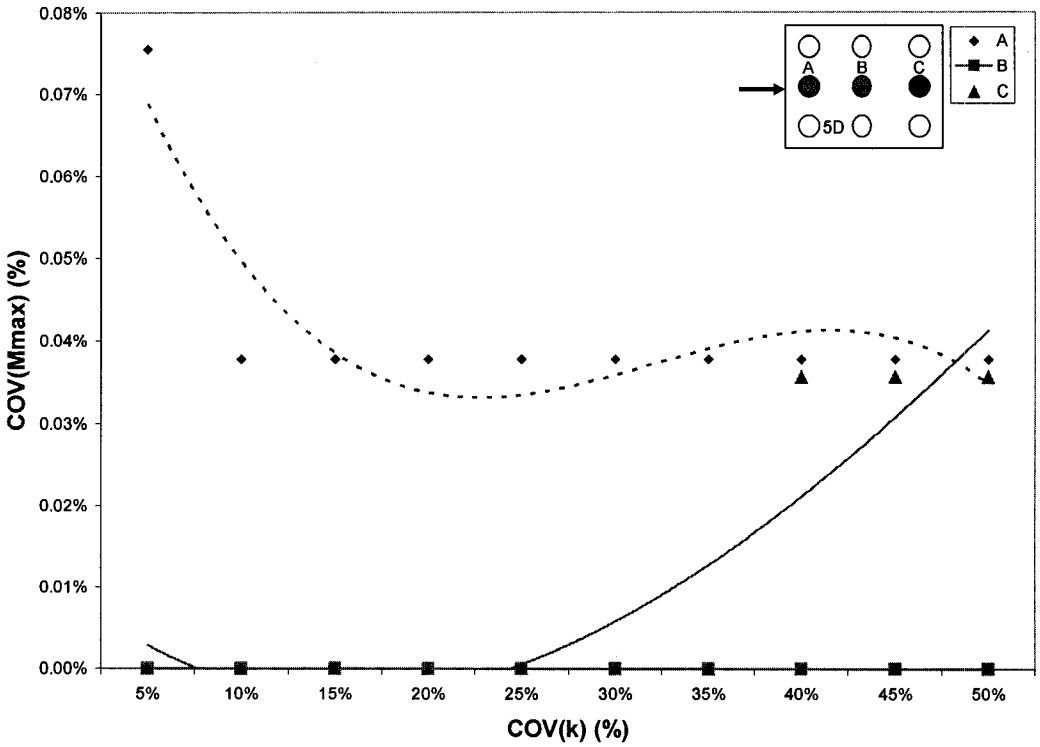

Fig. K.10(b) COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in hinged head long (10T) pile group with spacing (5D) at the optimum lateral load 958 kN.

K.1.6 Probabilistic modeling of laterally loaded hinged head long (10T) pile group with spacing (5D) and with 'γ'' as varying random design variable

Table K.21. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 685 kN and 958 kN.

			P=685 kN (74, 76, 78 kN)				P=958 kN (100, 110, 110 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00303	94.78	97.51	100.3	0.00476	132.5	136.4	140.2
45%	7.049025	3.245	0.00303	94.78	97.51	100.3	0.00476	132.5	136.4	140.2
40%	5.5696	3.54	0.00303	94.78	97.51	100.3	0.00476	132.5	136.4	140.2
35%	4.264225	3.835	0.00303	94.78	97.51	100.3	0.00475	132.5	136.4	140.2
30%	3.1329	4.13	0.00303	94.78	97.51	100.3	0.00475	132.5	136.4	140.2
25%	2.175625	4.425	0.00303	94.78	97.51	100.3	0.00475	132.5	136.4	140.2
20%	1.3924	4.72	0.00302	94.78	97.51	100.3	0.00475	132.5	136.4	140.2
15%	0.783225	5.015	0.00302	94.78	97.51	100.3	0.00475	132.5	136.4	140.2
10%	0.3481	5.31	0.00302	94.78	97.51	100.3	0.00474	132.5	136.4	140.2
5%	0.087025	5.605	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
0%	0	5.9	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
5%	0.087025	6.195	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
10%	0.3481	6.49	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
15%	0.783225	6.785	0.00302	94.78	97.51	100.3	0.00474	132.4	136.4	140.2
20%	1.3924	7.08	0.00302	94.78	97.51	100.3	0.00473	132.4	136.4	140.2
25%	2.175625	7.375	0.00301	94.78	97.51	100.3	0.00473	132.4	136.4	140.2
30%	3.1329	7.67	0.00301	94.78	97.51	100.3	0.00473	132.4	136.4	140.2
35%	4.264225	7.965	0.00301	94.78	97.51	100.3	0.00473	132.4	136.4	140.2
40%	5.5696	8.26	0.00301	94.78	97.51	100.3	0.00473	132.4	136.4	140.2
45%	7.049025	8.555	0.00301	94.78	97.51	100.3	0.00473	132.4	136.4	140.2
50%	8.7025	8.85	0.00301	94.78	97.51	100.3	0.00472	132.4	136.4	140.2

Table K.22. Values of Y_{Top} and M_{Max} for rows A, B, C of hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1130 kN and 1364 kN.

			P=1130 kN (120, 130, 130 kN)				P=1364 kN (150, 150, 160 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00597	156	160.9	165.8	0.00801	188	194.2	200.4
45%	7.049025	3.245	0.00597	156	160.9	165.8	0.008	188	194.2	200.4
40%	5.5696	3.54	0.00597	156	160.9	165.8	0.008	188	194.2	200.4
35%	4.264225	3.835	0.00597	156	160.9	165.8	0.008	188	194.2	200.4
30%	3.1329	4.13	0.00596	156	160.9	165.8	0.008	188	194.2	200.4
25%	2.175625	4.425	0.00596	156	160.9	165.8	0.00799	188	194.2	200.4
20%	1.3924	4.72	0.00596	156	160.9	165.8	0.00799	188	194.2	200.4
15%	0.783225	5.015	0.00596	156	160.9	165.8	0.00798	188	194.2	200.4
10%	0.3481	5.31	0.00595	156	160.9	165.7	0.00798	188	194.2	200.4
5%	0.087025	5.605	0.00595	156	160.9	165.7	0.00798	188	194.2	200.4
0%	0	5.9	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
5%	0.087025	6.195	0.00595	156	160.9	165.7	0.00797	188	194.2	200.4
10%	0.3481	6.49	0.00594	156	160.9	165.7	0.00797	188	194.2	200.4
15%	0.783225	6.785	0.00594	156	160.9	165.7	0.00796	188	194.2	200.4
20%	1.3924	7.08	0.00594	156	160.9	165.7	0.00796	188	194.2	200.4
25%	2.175625	7.375	0.00594	156	160.9	165.7	0.00795	188	194.2	200.4
30%	3.1329	7.67	0.00593	156	160.9	165.7	0.00795	188	194.2	200.4
35%	4.264225	7.965	0.00593	156	160.9	165.7	0.00795	188	194.2	200.4
40%	5.5696	8.26	0.00593	156	160.9	165.7	0.00794	188	194.2	200.4
45%	7.049025	8.555	0.00593	156	160.9	165.7	0.00794	188	194.2	200.4
50%	8.7025	8.85	0.00592	156	160.9	165.7	0.00794	188	194.2	200.4

Table K.23(a) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 685 kN and 958 kN.

		P=685 kN		P=958 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	0.00E+00	0.000%
10%	0.3481	0.00E+00	0.000%	0.00E+00	0.000%
15%	0.783225	0.00E+00	0.000%	2.50E-11	0.105%
20%	1.3924	0.00E+00	0.000%	1.00E-10	0.211%
25%	2.175625	1.00E-10	0.331%	1.00E-10	0.211%
30%	3.1329	1.00E-10	0.331%	1.00E-10	0.211%
35%	4.264225	1.00E-10	0.331%	1.00E-10	0.211%
40%	5.5696	1.00E-10	0.331%	2.25E-10	0.316%
45%	7.049025	1.00E-10	0.331%	2.25E-10	0.316%
50%	8.7025	1.00E-10	0.331%	4.00E-10	0.422%

Table K.23(b) Value of COV(Y_{Top}) for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1130 kN and 1364 kN.

		P=1130 kN		P=1364 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	2.50E-11	0.063%
10%	0.3481	2.50E-11	0.084%	2.50E-11	0.063%
15%	0.783225	1.00E-10	0.168%	1.00E-10	0.125%
20%	1.3924	1.00E-10	0.168%	2.25E-10	0.188%
25%	2.175625	1.00E-10	0.168%	4.00E-10	0.251%
30%	3.1329	2.25E-10	0.252%	6.25E-10	0.314%
35%	4.264225	4.00E-10	0.336%	6.25E-10	0.314%
40%	5.5696	4.00E-10	0.336%	9.00E-10	0.376%
45%	7.049025	4.00E-10	0.336%	9.00E-10	0.376%
50%	8.7025	6.25E-10	0.420%	1.23E-09	0.439%

Table K.24(a) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 685 kN.

		P=685 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.3924	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.175625	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.1329	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.264225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.5696	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	7.049025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
50%	8.7025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%

Table K.24(b) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 958 kN.

		P=958 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
15%	0.783225	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
20%	1.3924	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
25%	2.175625	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
30%	3.1329	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
35%	4.264225	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
40%	5.5696	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
45%	7.049025	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%
50%	8.7025	2.50E-03	0.00E+00	0.00E+00	0.04%	0.00%	0.00%

Table K.24(c) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1130 kN.

		P=1130 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
20%	1.3924	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
25%	2.175625	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
30%	3.1329	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
35%	4.264225	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
40%	5.5696	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
45%	7.049025	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%
50%	8.7025	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.03%

Table K.24(d) Value of COV(M_{Max}) for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1364 kN.

		P=1364 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	0.3481	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
15%	0.783225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
20%	1.3924	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
25%	2.175625	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
30%	3.1329	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
35%	4.264225	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
40%	5.5696	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
45%	7.049025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
50%	8.7025	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%

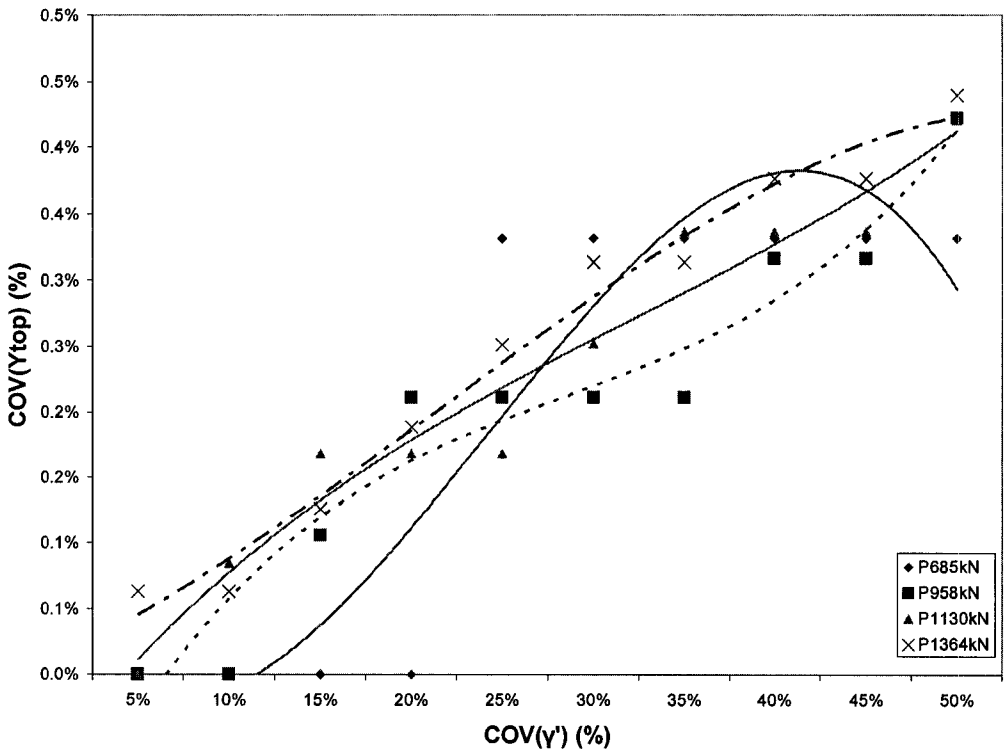

Fig. K.11 COV(Y_{Top}) for varying COV(γ') in hinged head long (10T) pile group with spacing (5D).

Note: Value of COV(M_{MAX}) is zero for pile rows A, B, C with varying COV(γ') in hinged head long (10T) pile group with spacing (5D).

K.2 Reliability analysis of hinged head long pile (10T) group with spacing (5D)

K.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 685 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00998 \text{ m} \quad \text{and} \quad VAR(Y_{top}^{Resist}) = 6.76E\text{-}06 \text{ m}^2$$

Table K.25 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 685 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	4.00E-10	6.76E-06	3.84	1.10E-08	6.77E-06	3.84
10%	6.76E-06	2.02E-09	6.76E-06	3.84	4.62E-08	6.81E-06	3.83
15%	6.76E-06	4.90E-09	6.76E-06	3.84	1.02E-07	6.86E-06	3.81
20%	6.76E-06	9.03E-09	6.77E-06	3.84	1.89E-07	6.95E-06	3.79
25%	6.76E-06	4.90E-09	6.76E-06	3.84	3.19E-07	7.08E-06	3.75
30%	6.76E-06	1.22E-09	6.76E-06	3.84	4.90E-07	7.25E-06	3.71
35%	6.76E-06	2.50E-11	6.76E-06	3.84	7.23E-07	7.48E-06	3.65
40%	6.76E-06	2.02E-09	6.76E-06	3.84	1.03E-06	7.79E-06	3.58
45%	6.76E-06	8.10E-09	6.77E-06	3.84	1.45E-06	8.21E-06	3.48
50%	6.76E-06	2.89E-08	6.79E-06	3.83	1.97E-06	8.73E-06	3.38

Table K.26 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 685 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-09	6.76E-06	3.84	9.03E-09	6.77E-06	3.84
10%	6.76E-06	1.10E-08	6.77E-06	3.84	3.42E-08	6.79E-06	3.83
15%	6.76E-06	2.56E-08	6.79E-06	3.83	8.12E-08	6.84E-06	3.82
20%	6.76E-06	4.84E-08	6.81E-06	3.82	1.48E-07	6.91E-06	3.80
25%	6.76E-06	7.84E-08	6.84E-06	3.82	2.40E-07	7.00E-06	3.77
30%	6.76E-06	1.09E-07	6.87E-06	3.81	3.60E-07	7.12E-06	3.74
35%	6.76E-06	1.52E-07	6.91E-06	3.80	5.18E-07	7.28E-06	3.70
40%	6.76E-06	1.94E-07	6.95E-06	3.78	7.14E-07	7.47E-06	3.65
45%	6.76E-06	2.50E-07	7.01E-06	3.77	9.70E-07	7.73E-06	3.59
50%	6.76E-06	3.14E-07	7.07E-06	3.75	1.31E-06	8.07E-06	3.51

Table K.27 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 685 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.84	0.00E+00	6.76E-06	3.84
10%	6.76E-06	0.00E+00	6.76E-06	3.84	0.00E+00	6.76E-06	3.84
15%	6.76E-06	0.00E+00	6.76E-06	3.84	0.00E+00	6.76E-06	3.84
20%	6.76E-06	0.00E+00	6.76E-06	3.84	2.50E-11	6.76E-06	3.84
25%	6.76E-06	1.00E-10	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
30%	6.76E-06	1.00E-10	6.76E-06	3.84	1.00E-10	6.76E-06	3.84
35%	6.76E-06	1.00E-10	6.76E-06	3.84	2.25E-10	6.76E-06	3.84
40%	6.76E-06	1.00E-10	6.76E-06	3.84	4.00E-10	6.76E-06	3.84
45%	6.76E-06	1.00E-10	6.76E-06	3.84	4.00E-10	6.76E-06	3.84
50%	6.76E-06	1.00E-10	6.76E-06	3.84	4.90E-09	6.76E-06	3.84

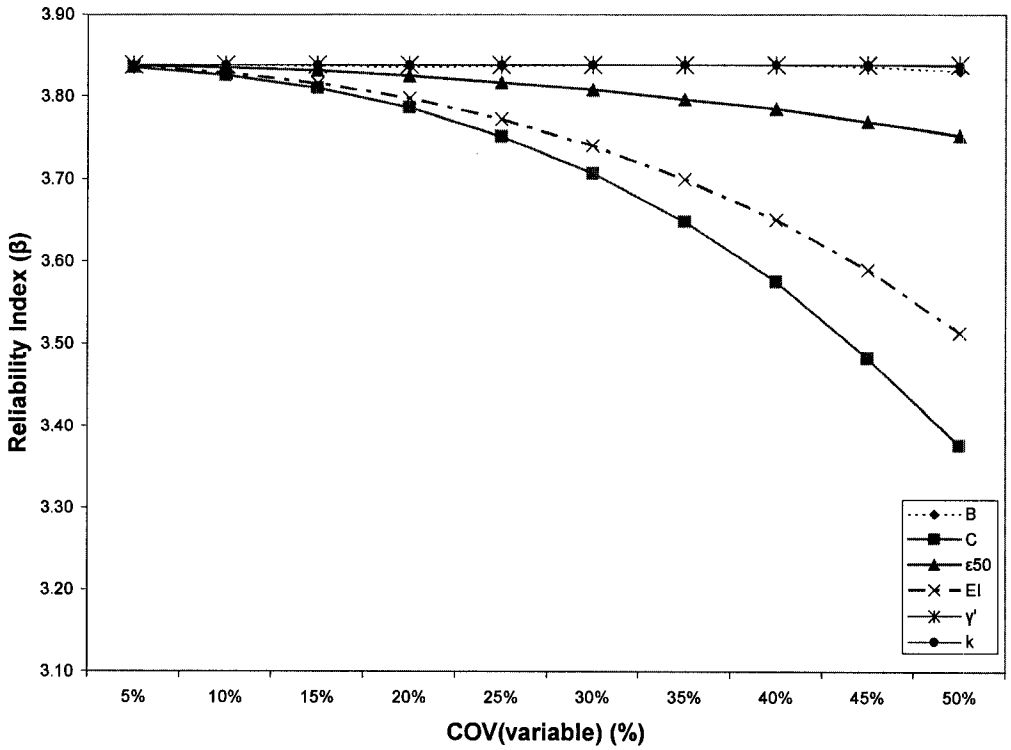

Fig. K.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (5D) at 685 kN lateral load.

For lateral load 958 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00826 \text{ m}$$

Table K.28 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 958 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	9.00E-10	6.76E-06	3.18	2.72E-08	6.79E-06	3.17
10%	6.76E-06	4.22E-09	6.76E-06	3.18	1.12E-07	6.87E-06	3.15
15%	6.76E-06	1.00E-08	6.77E-06	3.17	2.70E-07	7.03E-06	3.12
20%	6.76E-06	1.69E-08	6.78E-06	3.17	5.18E-07	7.28E-06	3.06
25%	6.76E-06	7.23E-09	6.77E-06	3.18	8.93E-07	7.65E-06	2.99
30%	6.76E-06	1.00E-10	6.76E-06	3.18	1.43E-06	8.19E-06	2.89
35%	6.76E-06	6.40E-09	6.77E-06	3.18	2.21E-06	8.97E-06	2.76
40%	6.76E-06	3.80E-08	6.80E-06	3.17	3.28E-06	1.00E-05	2.61
45%	6.76E-06	1.30E-07	6.89E-06	3.15	4.84E-06	1.16E-05	2.43
50%	6.76E-06	3.19E-07	7.08E-06	3.10	7.10E-06	1.39E-05	2.22

Table K.29 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 958 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	6.40E-09	6.77E-06	3.18	2.40E-08	6.78E-06	3.17
10%	6.76E-06	2.72E-08	6.79E-06	3.17	9.00E-08	6.85E-06	3.16
15%	6.76E-06	6.25E-08	6.82E-06	3.16	2.07E-07	6.97E-06	3.13
20%	6.76E-06	1.12E-07	6.87E-06	3.15	3.72E-07	7.13E-06	3.09
25%	6.76E-06	1.81E-07	6.94E-06	3.14	6.08E-07	7.37E-06	3.04
30%	6.76E-06	2.70E-07	7.03E-06	3.12	9.03E-07	7.66E-06	2.98
35%	6.76E-06	3.78E-07	7.14E-06	3.09	1.30E-06	8.06E-06	2.91
40%	6.76E-06	5.11E-07	7.27E-06	3.06	1.80E-06	8.56E-06	2.82
45%	6.76E-06	6.56E-07	7.42E-06	3.03	2.46E-06	9.22E-06	2.72
50%	6.76E-06	8.10E-07	7.57E-06	3.00	3.33E-06	1.01E-05	2.60

Table K.30 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 958 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.18	2.50E-11	6.76E-06	3.18
10%	6.76E-06	0.00E+00	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
15%	6.76E-06	2.50E-11	6.76E-06	3.18	1.00E-10	6.76E-06	3.18
20%	6.76E-06	1.00E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
25%	6.76E-06	1.00E-10	6.76E-06	3.18	2.25E-10	6.76E-06	3.18
30%	6.76E-06	1.00E-10	6.76E-06	3.18	4.00E-10	6.76E-06	3.18
35%	6.76E-06	1.00E-10	6.76E-06	3.18	6.25E-10	6.76E-06	3.18
40%	6.76E-06	2.25E-10	6.76E-06	3.18	9.00E-10	6.76E-06	3.18
45%	6.76E-06	2.25E-10	6.76E-06	3.18	1.22E-09	6.76E-06	3.18
50%	6.76E-06	4.00E-10	6.76E-06	3.18	2.02E-09	6.76E-06	3.18

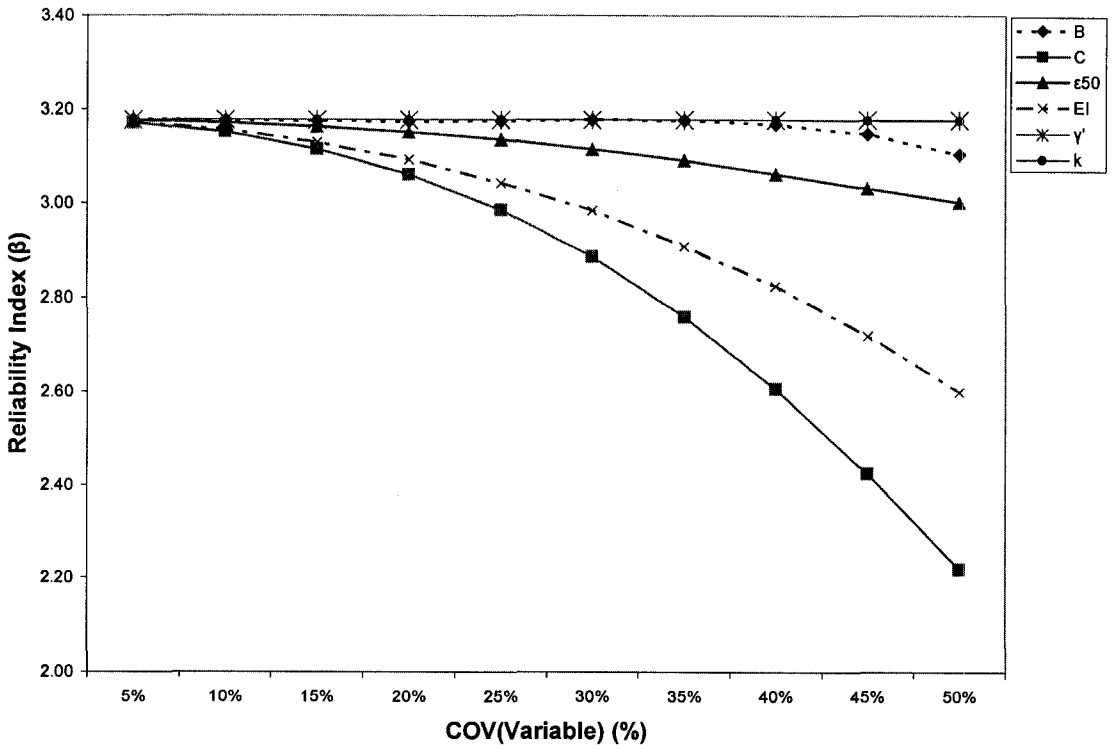

Fig. K.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (5D) at 958 kN lateral load.

For lateral load 1130 kN

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00705 \text{ m}$$

Table K.31 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 1130 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	9.00E-10	6.76E-06	2.71	6.00E-08	6.82E-06	2.70
10%	6.76E-06	3.60E-09	6.76E-06	2.71	2.40E-07	7.00E-06	2.66
15%	6.76E-06	9.03E-09	6.77E-06	2.71	5.55E-07	7.32E-06	2.61
20%	6.76E-06	1.56E-08	6.78E-06	2.71	1.04E-06	7.80E-06	2.52
25%	6.76E-06	6.25E-10	6.76E-06	2.71	1.77E-06	8.53E-06	2.41
30%	6.76E-06	1.21E-08	6.77E-06	2.71	2.84E-06	9.60E-06	2.28
35%	6.76E-06	7.29E-08	6.83E-06	2.70	4.35E-06	1.11E-05	2.12
40%	6.76E-06	2.12E-07	6.97E-06	2.67	6.45E-06	1.32E-05	1.94
45%	6.76E-06	5.33E-07	7.29E-06	2.61	9.73E-06	1.65E-05	1.74
50%	6.76E-06	1.20E-06	7.96E-06	2.50	1.43E-05	2.10E-05	1.54

Table K.32 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1130 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.10E-08	6.77E-06	2.71	3.61E-08	6.80E-06	2.70
10%	6.76E-06	4.41E-08	6.80E-06	2.70	1.44E-07	6.90E-06	2.68
15%	6.76E-06	9.92E-08	6.86E-06	2.69	3.31E-07	7.09E-06	2.65
20%	6.76E-06	1.72E-07	6.93E-06	2.68	6.01E-07	7.36E-06	2.60
25%	6.76E-06	2.76E-07	7.04E-06	2.66	9.80E-07	7.74E-06	2.53
30%	6.76E-06	3.91E-07	7.15E-06	2.64	1.49E-06	8.25E-06	2.45
35%	6.76E-06	5.40E-07	7.30E-06	2.61	2.19E-06	8.95E-06	2.36
40%	6.76E-06	7.14E-07	7.47E-06	2.58	3.06E-06	9.82E-06	2.25
45%	6.76E-06	9.22E-07	7.68E-06	2.54	4.22E-06	1.10E-05	2.13
50%	6.76E-06	1.17E-06	7.93E-06	2.50	5.78E-06	1.25E-05	1.99

Table K.33 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 1130 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
10%	6.76E-06	2.50E-11	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
15%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
20%	6.76E-06	1.00E-10	6.76E-06	2.71	0.00E+00	6.76E-06	2.71
25%	6.76E-06	1.00E-10	6.76E-06	2.71	2.50E-11	6.76E-06	2.71
30%	6.76E-06	2.25E-10	6.76E-06	2.71	1.00E-10	6.76E-06	2.71
35%	6.76E-06	4.00E-10	6.76E-06	2.71	6.25E-10	6.76E-06	2.71
40%	6.76E-06	4.00E-10	6.76E-06	2.71	9.00E-10	6.76E-06	2.71
45%	6.76E-06	4.00E-10	6.76E-06	2.71	1.60E-09	6.76E-06	2.71
50%	6.76E-06	6.25E-10	6.76E-06	2.71	2.50E-09	6.76E-06	2.71

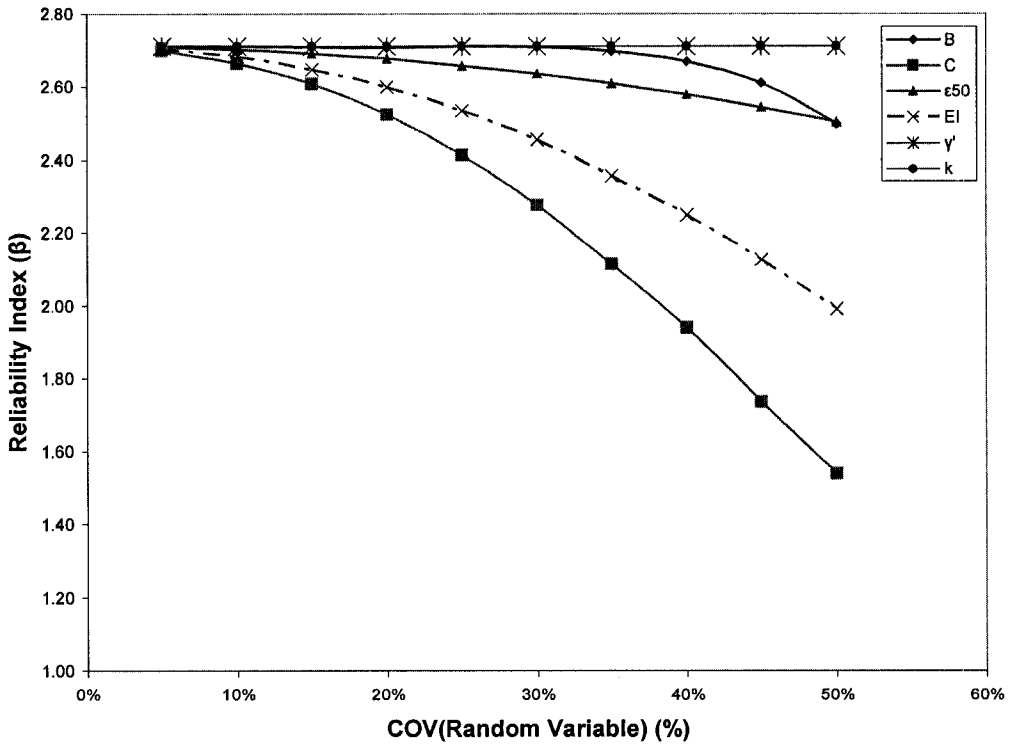

Fig. K.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (5D) at 1130 kN lateral load.

For lateral load 1364 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00503 \text{ m}$$

Table K.34 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 1364 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.00E-10	6.76E-06	1.93	1.44E-07	6.90E-06	1.91
10%	6.76E-06	6.25E-10	6.76E-06	1.93	5.93E-07	7.35E-06	1.85
15%	6.76E-06	1.60E-09	6.76E-06	1.93	1.38E-06	8.14E-06	1.76
20%	6.76E-06	3.03E-09	6.76E-06	1.93	2.56E-06	9.32E-06	1.65
25%	6.76E-06	1.96E-08	6.78E-06	1.93	4.26E-06	1.10E-05	1.51
30%	6.76E-06	1.37E-07	6.90E-06	1.92	6.81E-06	1.36E-05	1.37
35%	6.76E-06	4.29E-07	7.19E-06	1.88	1.02E-05	1.70E-05	1.22
40%	6.76E-06	1.11E-06	7.87E-06	1.79	1.54E-05	2.22E-05	1.07
45%	6.76E-06	2.59E-06	9.35E-06	1.64	2.26E-05	2.93E-05	0.93
50%	6.76E-06	1.00E-05	1.68E-05	1.23	3.51E-05	4.19E-05	0.78

Table K.35 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1364 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.69E-08	6.78E-06	1.93	7.02E-08	6.83E-06	1.92
10%	6.76E-06	7.02E-08	6.83E-06	1.92	2.76E-07	7.04E-06	1.90
15%	6.76E-06	1.56E-07	6.92E-06	1.91	6.40E-07	7.40E-06	1.85
20%	6.76E-06	2.86E-07	7.05E-06	1.89	1.17E-06	7.93E-06	1.79
25%	6.76E-06	4.49E-07	7.21E-06	1.87	1.90E-06	8.66E-06	1.71
30%	6.76E-06	6.48E-07	7.41E-06	1.85	2.84E-06	9.60E-06	1.62
35%	6.76E-06	8.74E-07	7.63E-06	1.82	4.26E-06	1.10E-05	1.51
40%	6.76E-06	1.17E-06	7.93E-06	1.79	5.71E-06	1.25E-05	1.42
45%	6.76E-06	1.45E-06	8.21E-06	1.76	7.90E-06	1.47E-05	1.31
50%	6.76E-06	1.78E-06	8.54E-06	1.72	1.10E-05	1.78E-05	1.19

Table K.36 Reliability Index connected to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 1364 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
10%	6.76E-06	2.50E-11	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
15%	6.76E-06	1.00E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
20%	6.76E-06	2.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
25%	6.76E-06	4.00E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
30%	6.76E-06	6.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
35%	6.76E-06	6.25E-10	6.76E-06	1.93	0.00E+00	6.76E-06	1.93
40%	6.76E-06	9.00E-10	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
45%	6.76E-06	9.00E-10	6.76E-06	1.93	2.50E-11	6.76E-06	1.93
50%	6.76E-06	1.23E-09	6.76E-06	1.93	9.00E-10	6.76E-06	1.93

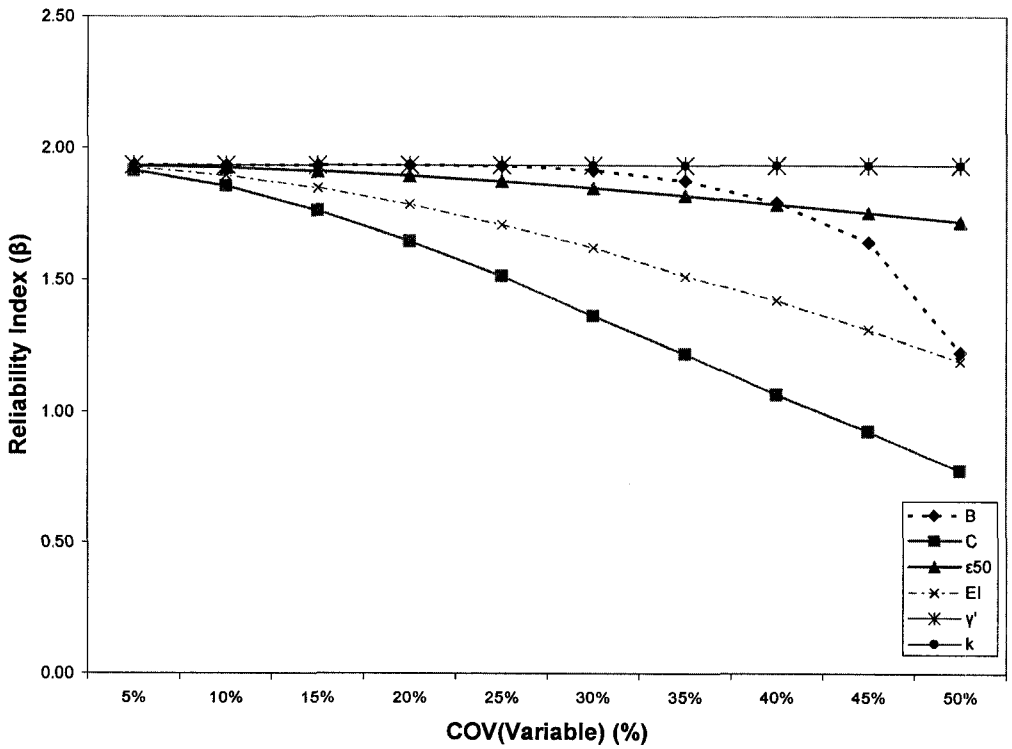

Fig. K.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in hinged head long (10T) pile group with spacing (5D) at 1364 kN lateral load.

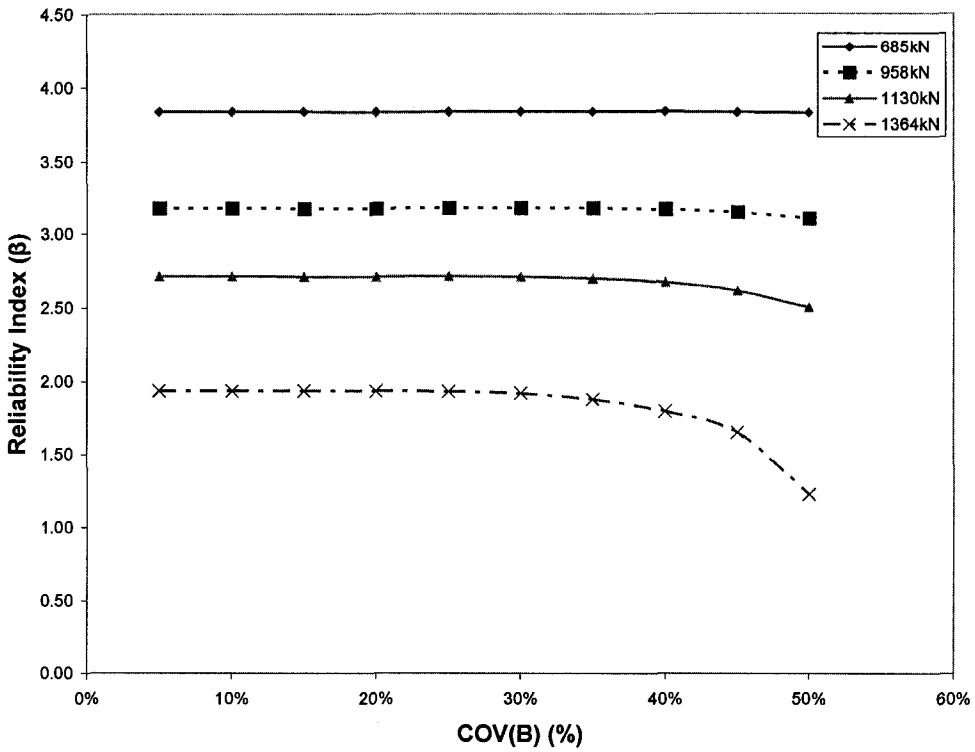

Fig. K.17 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'B'.

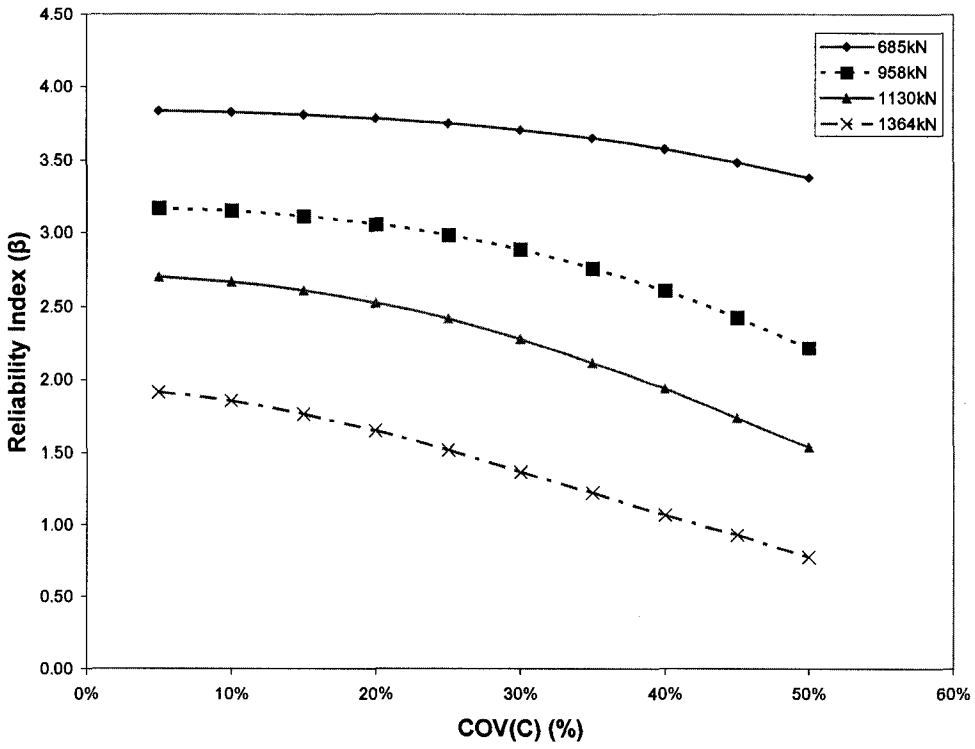

Fig. K.18 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'C'.

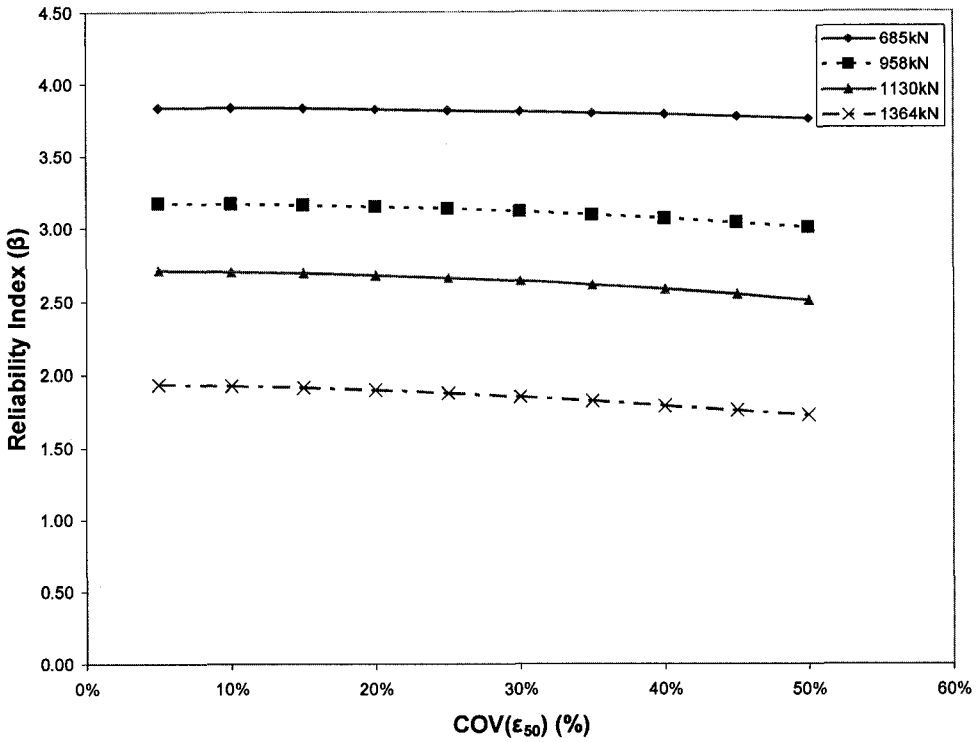

Fig. K.19 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}'.

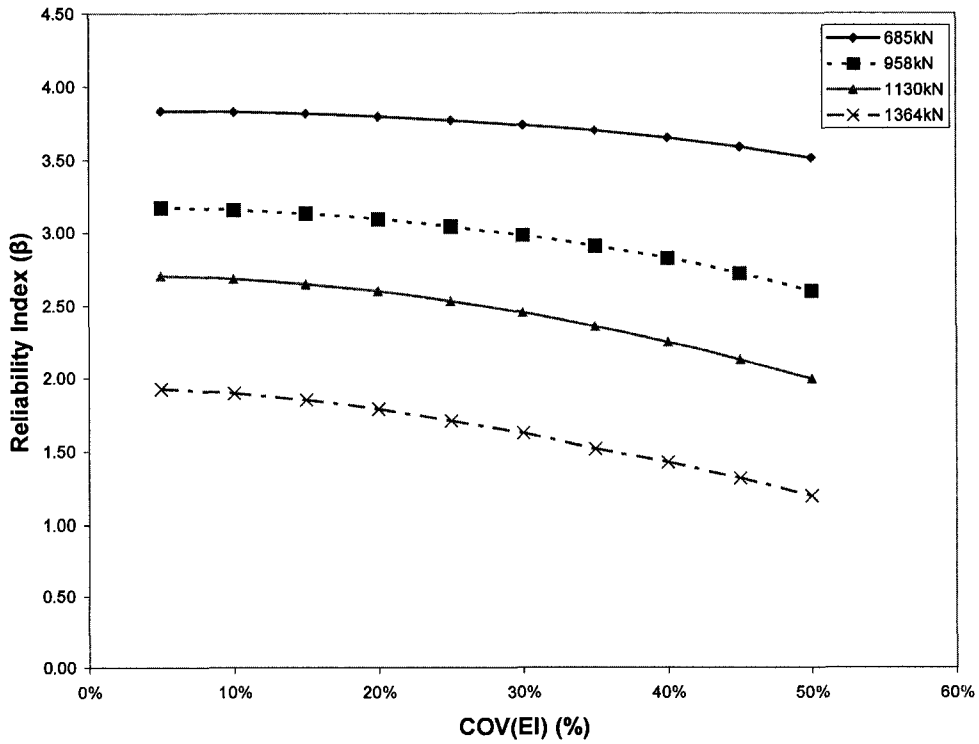

Fig. K.20 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'EI'.

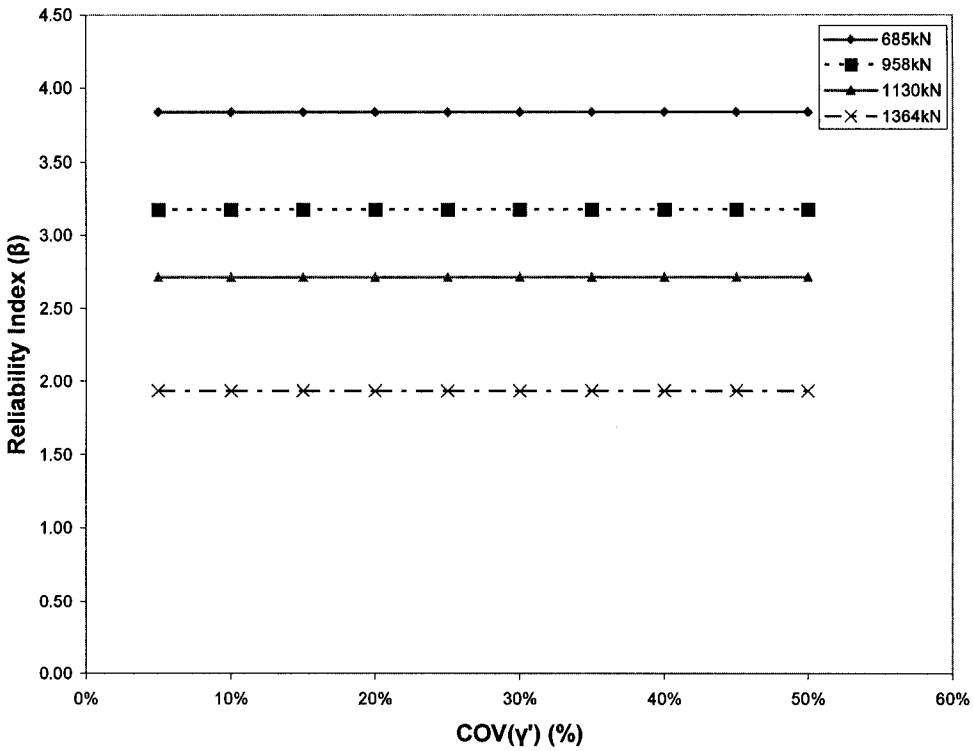

Fig. K.21 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'γ'.

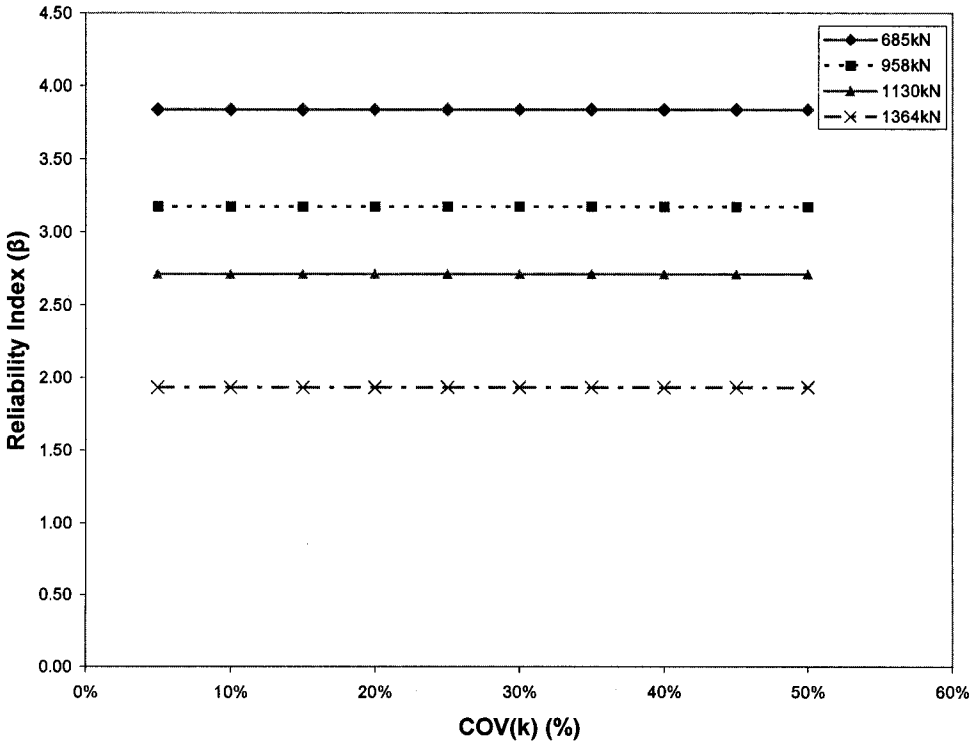

Fig. K.22 Reliability Index related to Y_{Top} for hinged head long (10T) pile group with spacing (5D) and with varying 'k'.

K.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 685 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 793.7 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table K.37 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 685 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) (kN-m)^2	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)	VAR ($M_{Max}^{Current}$) (kN-m)^2	VAR {g(M_{Max})} (kN-m)^2	Reliability Index (β)
5%	31969.44	0	31969.440	4.44	0	31969.440	4.44
10%	31969.44	0	31969.440	4.44	0	31969.440	4.44
15%	31969.44	0	31969.440	4.44	0	31969.440	4.44
20%	31969.44	0	31969.440	4.44	0.0025	31969.443	4.44
25%	31969.44	0	31969.440	4.44	0.001	31969.441	4.44
30%	31969.44	0	31969.440	4.44	0.01	31969.450	4.44
35%	31969.44	0	31969.440	4.44	0.01	31969.450	4.44
40%	31969.44	0	31969.440	4.44	0.0225	31969.463	4.44
45%	31969.44	0.0025	31969.443	4.44	0.04	31969.480	4.44
50%	31969.44	0.0225	31969.463	4.44	0.245025	31969.685	4.44

Table K.38 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 685 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
10%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
15%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
20%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
25%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
30%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
35%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
40%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
45%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
50%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44

Table K.39 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 685 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
10%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
15%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
20%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
25%	31969.44	0.00E+00	31969.440	4.44	0.00E+00	31969.440	4.44
30%	31969.44	0.00E+00	31969.440	4.44	2.50E-03	31969.443	4.44
35%	31969.44	0.00E+00	31969.440	4.44	2.50E-03	31969.443	4.44
40%	31969.44	0.00E+00	31969.440	4.44	2.50E-03	31969.443	4.44
45%	31969.44	0.00E+00	31969.440	4.44	1.00E-02	31969.450	4.44
50%	31969.44	0.00E+00	31969.440	4.44	1.56E-02	31969.456	4.44

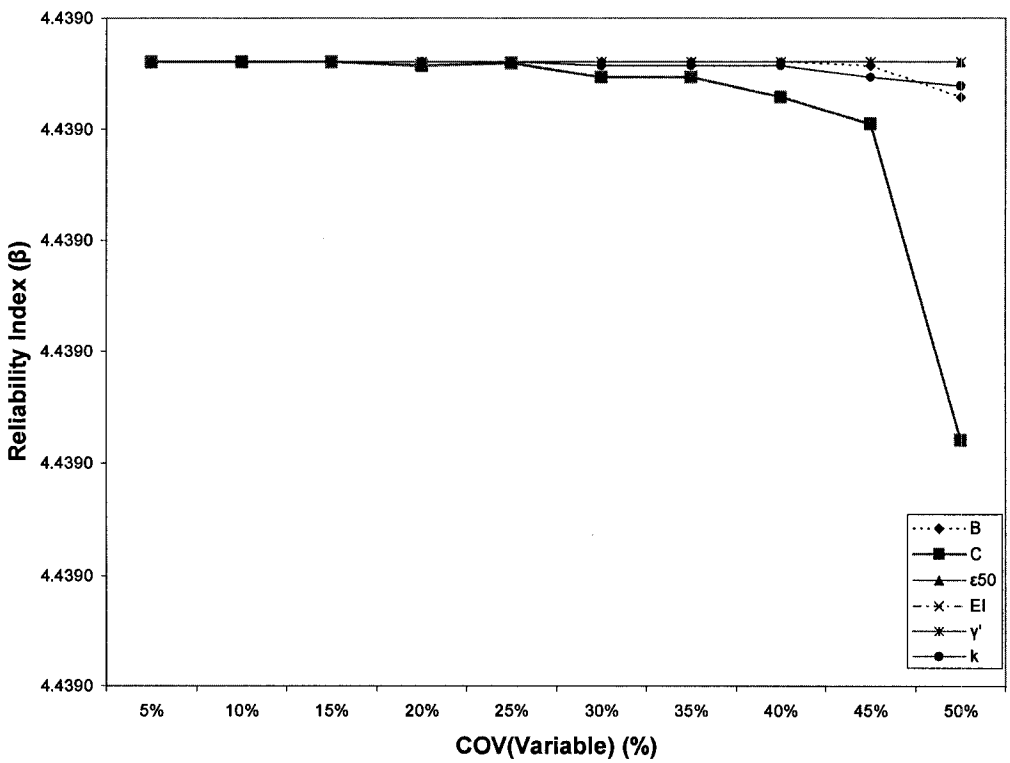

Fig. K.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (5D) at 685 kN lateral load.

For lateral load 958 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 755.8 \text{ kN.m}$$

Table K.40 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 958 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.22	0.01	31969.45	4.22
10%	31969.44	0.0025	31969.44	4.22	0.0025	31969.44	4.22
15%	31969.44	0.0025	31969.44	4.22	0.01	31969.45	4.22
20%	31969.44	0.01	31969.45	4.22	0.0225	31969.46	4.22
25%	31969.44	0.0225	31969.46	4.22	0.04	31969.48	4.22
30%	31969.44	0.0625	31969.50	4.22	0.0625	31969.50	4.22
35%	31969.44	0.09	31969.53	4.22	0.09	31969.53	4.22
40%	31969.44	0.1225	31969.56	4.22	0.1225	31969.56	4.22
45%	31969.44	0.16	31969.60	4.22	0.1225	31969.56	4.22
50%	31969.44	0.2025	31969.64	4.22	7.0225	31976.46	4.22

Table K.41 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 958 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.22	0	31969.44	4.22
10%	31969.44	0.0025	31969.44	4.22	0	31969.44	4.22
15%	31969.44	0.0025	31969.44	4.22	0.0025	31969.44	4.22
20%	31969.44	0.0025	31969.44	4.22	0.0025	31969.44	4.22
25%	31969.44	0.0025	31969.44	4.22	0.01	31969.45	4.22
30%	31969.44	0.01	31969.45	4.22	0.01	31969.45	4.22
35%	31969.44	0.01	31969.45	4.22	0.0025	31969.44	4.22
40%	31969.44	0.01	31969.45	4.22	0.01	31969.45	4.22
45%	31969.44	0.0025	31969.44	4.22	0.0025	31969.44	4.22
50%	31969.44	0.0025	31969.44	4.22	0.0025	31969.44	4.22

Table K.42 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 958 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	4.22	0.00E+00	31969.44	4.22
10%	31969.44	0.00E+00	31969.44	4.22	0.00E+00	31969.44	4.22
15%	31969.44	0.00E+00	31969.44	4.22	2.50E-03	31969.44	4.22
20%	31969.44	0.00E+00	31969.44	4.22	0.00E+00	31969.44	4.22
25%	31969.44	0.00E+00	31969.44	4.22	0.00E+00	31969.44	4.22
30%	31969.44	0.00E+00	31969.44	4.22	0.00E+00	31969.44	4.22
35%	31969.44	0.00E+00	31969.44	4.22	0.00E+00	31969.44	4.22
40%	31969.44	0.00E+00	31969.44	4.22	2.50E-03	31969.44	4.22
45%	31969.44	0.00E+00	31969.44	4.22	2.50E-03	31969.44	4.22
50%	31969.44	0.00E+00	31969.44	4.22	2.50E-03	31969.44	4.22

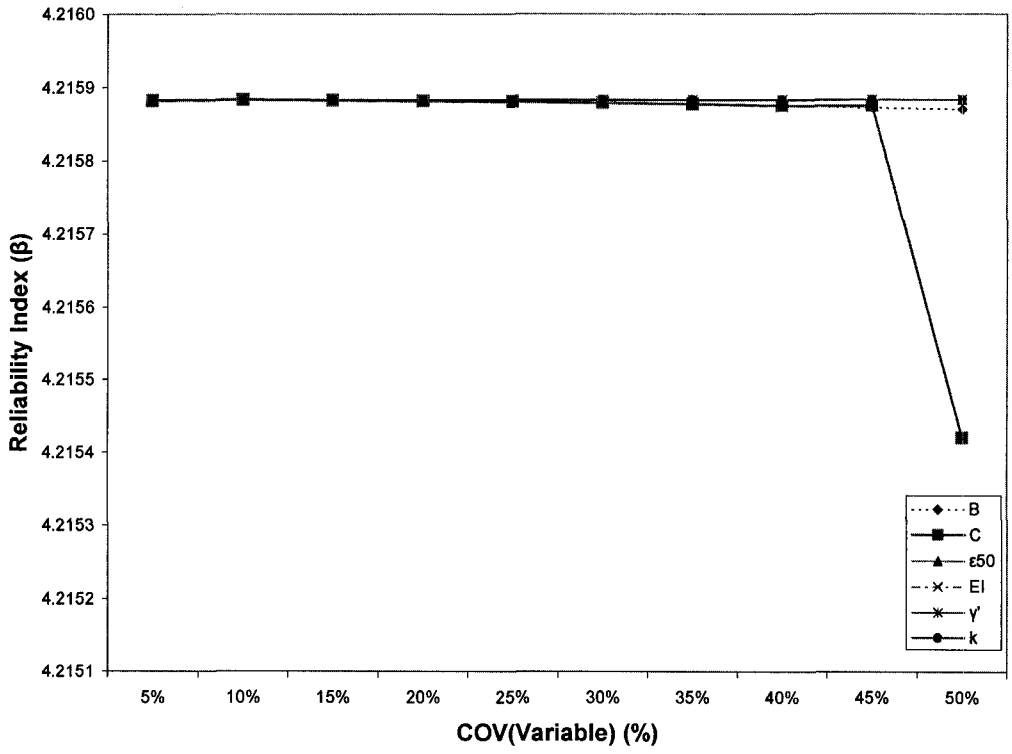

Fig. K.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (5D) at 958 kN lateral load.

For lateral load 1130 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 728.3 \text{ kN.m}$$

Table K.43 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 1130 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.01	31969.45	4.07	0.0225	31969.46	4.07
10%	31969.44	0.01	31969.45	4.07	0.0625	31969.50	4.07
15%	31969.44	0.0225	31969.46	4.07	0.1225	31969.56	4.07
20%	31969.44	0.0225	31969.46	4.07	0.1225	31969.56	4.07
25%	31969.44	0.0625	31969.50	4.07	0.1225	31969.56	4.07
30%	31969.44	0.09	31969.53	4.07	0.16	31969.60	4.07
35%	31969.44	0.1225	31969.56	4.07	0.16	31969.60	4.07
40%	31969.44	0.16	31969.60	4.07	0.7225	31970.16	4.07
45%	31969.44	0.2025	31969.64	4.07	24.01	31993.45	4.07
50%	31969.44	0.36	31969.80	4.07	89.3025	32058.74	4.07

Table K.44 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 1130 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0	31969.44	4.07	0	31969.44	4.07
10%	31969.44	0	31969.44	4.07	0	31969.44	4.07
15%	31969.44	0.01	31969.45	4.07	0	31969.44	4.07
20%	31969.44	0.01	31969.45	4.07	0	31969.44	4.07
25%	31969.44	0.0025	31969.44	4.07	0.0025	31969.44	4.07
30%	31969.44	0.0025	31969.44	4.07	0.0025	31969.44	4.07
35%	31969.44	0.0025	31969.44	4.07	0.0025	31969.44	4.07
40%	31969.44	0.0025	31969.44	4.07	0.01	31969.45	4.07
45%	31969.44	0	31969.44	4.07	0.01	31969.45	4.07
50%	31969.44	0	31969.44	4.07	0.01	31969.45	4.07

Table K.45 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 1130 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	4.07	0.00E+00	31969.44	4.07
10%	31969.44	0.00E+00	31969.44	4.07	0.00E+00	31969.44	4.07
15%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
20%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
25%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
30%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
35%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
40%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
45%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07
50%	31969.44	2.50E-03	31969.44	4.07	0.00E+00	31969.44	4.07

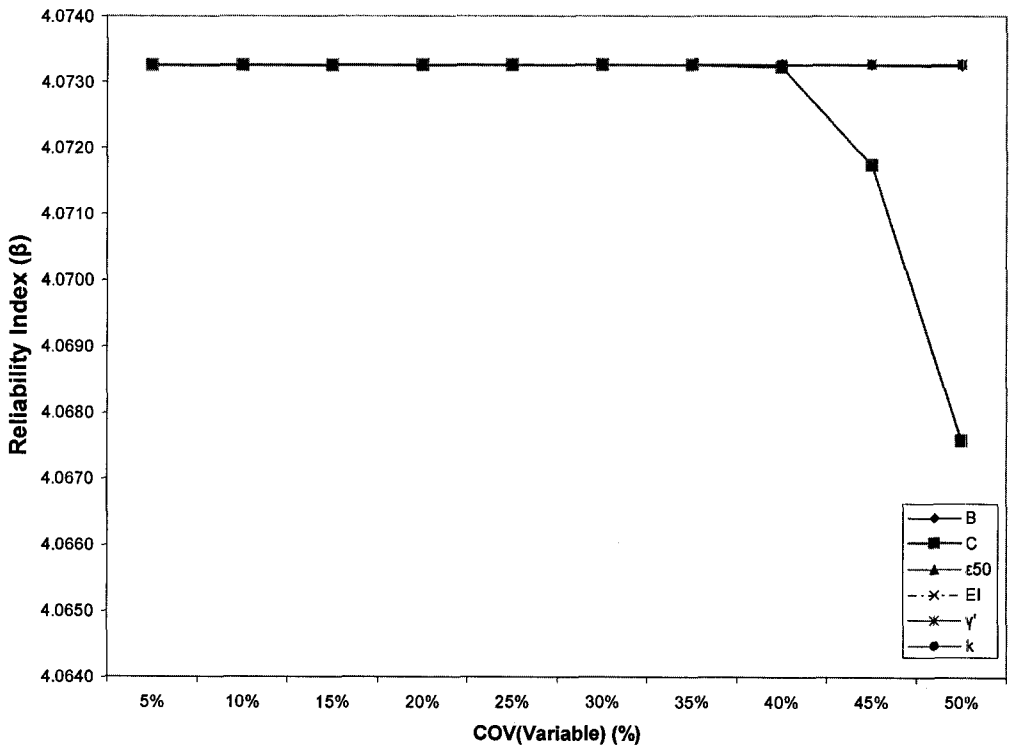

Fig. K.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (5D) at 1130 kN lateral load.

For lateral load 1364 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Current_o} = 693.6 \text{ kN.m}$$

Table K.46 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 1364 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	3.88	0.01	31969.45	3.88
10%	31969.44	0.0025	31969.44	3.88	0.0225	31969.46	3.88
15%	31969.44	0.0225	31969.46	3.88	0.0625	31969.50	3.88
20%	31969.44	0.0225	31969.46	3.88	0.2025	31969.64	3.88
25%	31969.44	0.04	31969.48	3.88	0.25	31969.69	3.88
30%	31969.44	0.1225	31969.56	3.88	1.1025	31970.54	3.88
35%	31969.44	0.16	31969.60	3.88	32.49	32001.93	3.88
40%	31969.44	0.3025	31969.74	3.88	115.5625	32085.00	3.87
45%	31969.44	0.36	31969.80	3.88	272.25	32241.69	3.86
50%	31969.44	238.7025	32208.14	3.86	556.96	32526.40	3.85

Table K.47 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 1364 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.443	3.88	0.0025	31969.443	3.88
10%	31969.44	0.0025	31969.443	3.88	0.01	31969.450	3.88
15%	31969.44	0.0025	31969.443	3.88	0.01	31969.450	3.88
20%	31969.44	0.0025	31969.443	3.88	0.01	31969.450	3.88
25%	31969.44	0.0025	31969.443	3.88	0.01	31969.450	3.88
30%	31969.44	0.0225	31969.463	3.88	0.01	31969.450	3.88
35%	31969.44	0.09	31969.530	3.88	0.0225	31969.463	3.88
40%	31969.44	0.0625	31969.503	3.88	0.0225	31969.463	3.88
45%	31969.44	0.0625	31969.503	3.88	0.0225	31969.463	3.88
50%	31969.44	0.04	31969.480	3.88	0.0225	31969.463	3.88

Table K.48 Reliability Index connected to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 1364 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
10%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
15%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
20%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
25%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
30%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
35%	31969.44	0.00E+00	31969.44	3.88	0.00E+00	31969.44	3.88
40%	31969.44	0.00E+00	31969.44	3.88	2.50E-03	31969.44	3.88
45%	31969.44	0.00E+00	31969.44	3.88	2.25E-02	31969.46	3.88
50%	31969.44	0.00E+00	31969.44	3.88	4.00E-02	31969.48	3.88

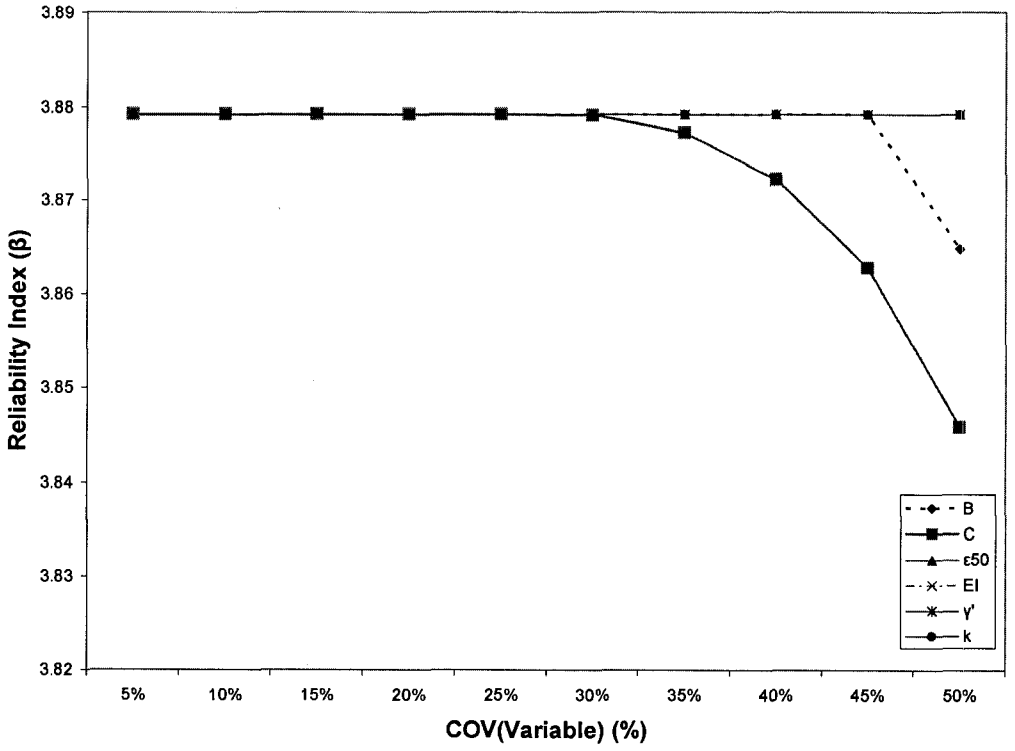

Fig. K.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of hinged head long (10T) pile group with spacing (5D) at 1364 kN lateral load.

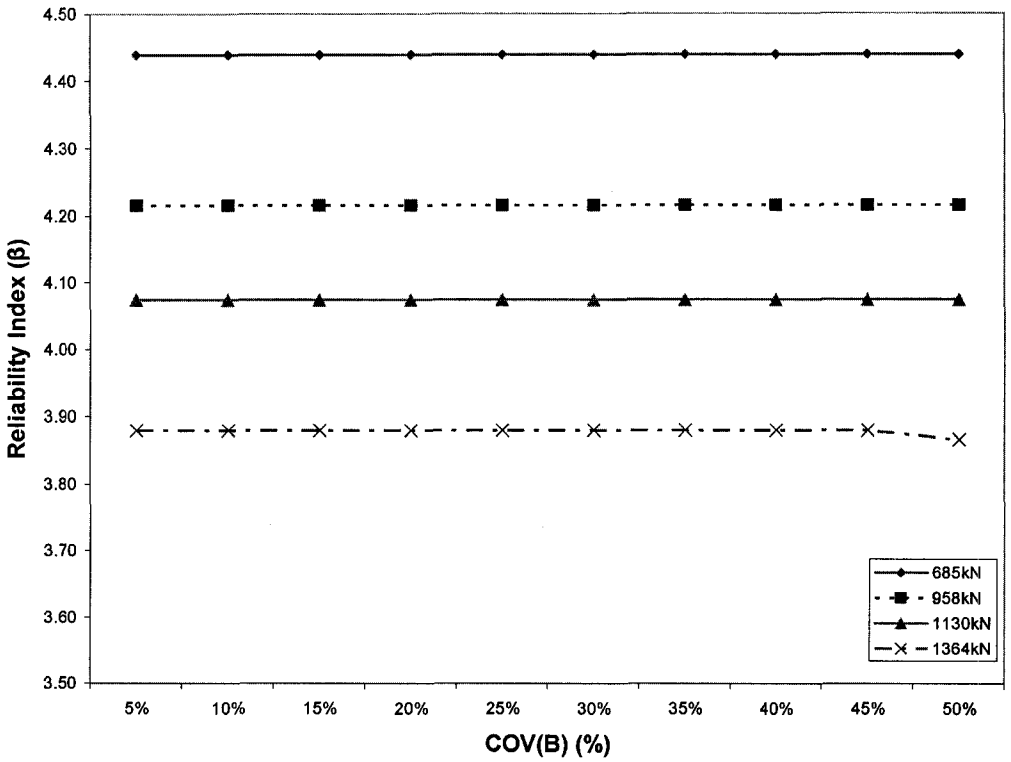

Fig. K.27 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'B'.

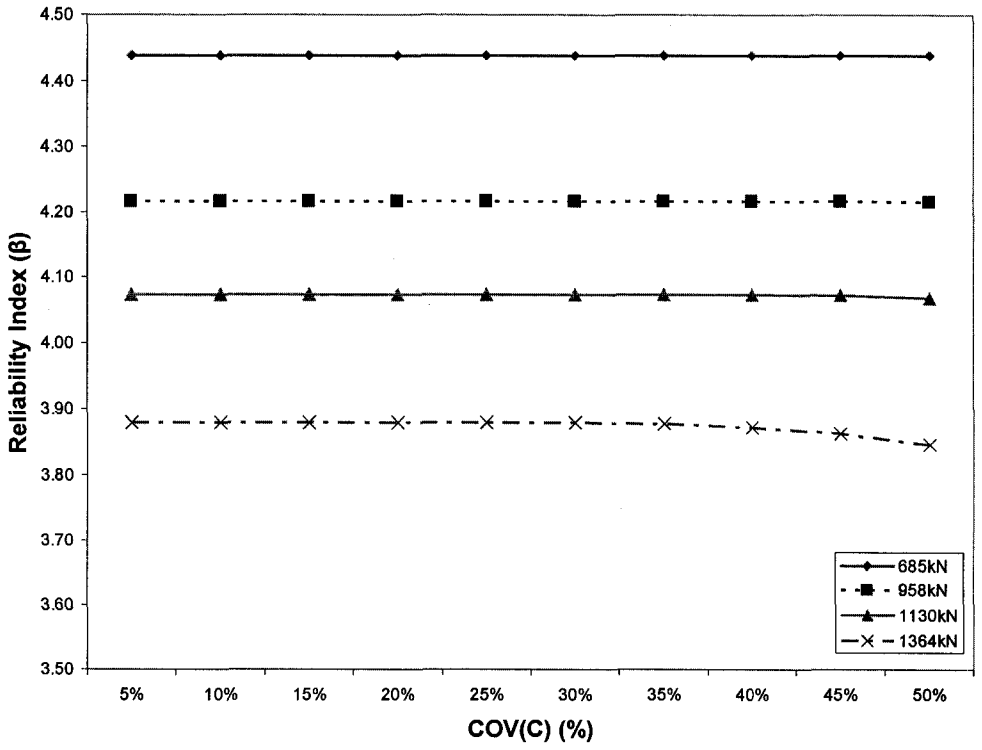

Fig. K.28 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'C'.

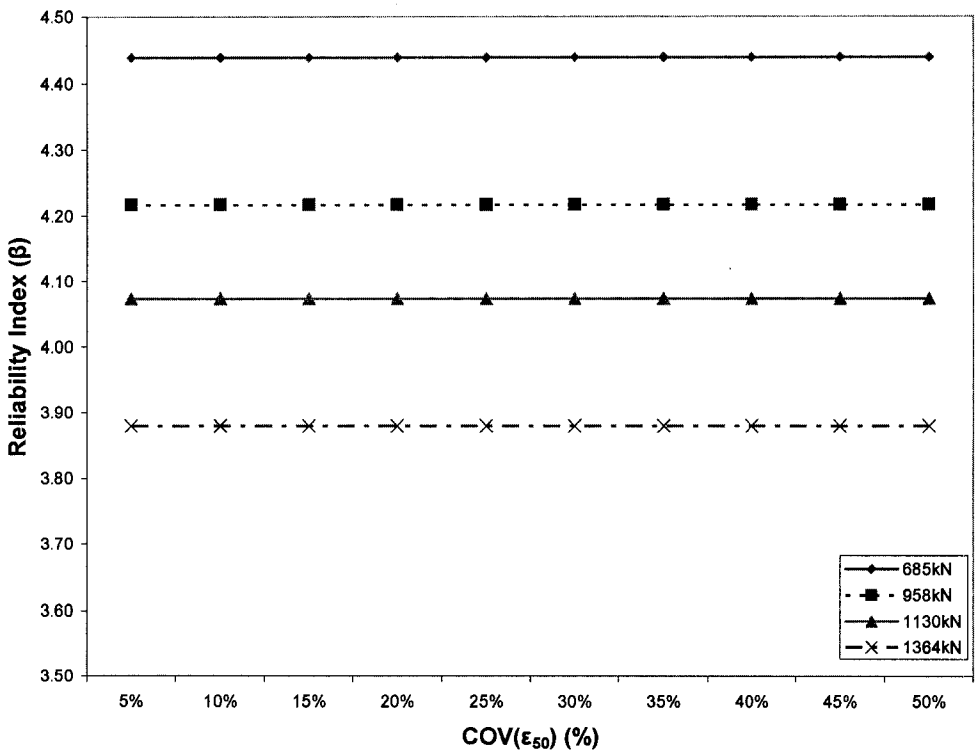

Fig. K.29 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'ε_{50}'.

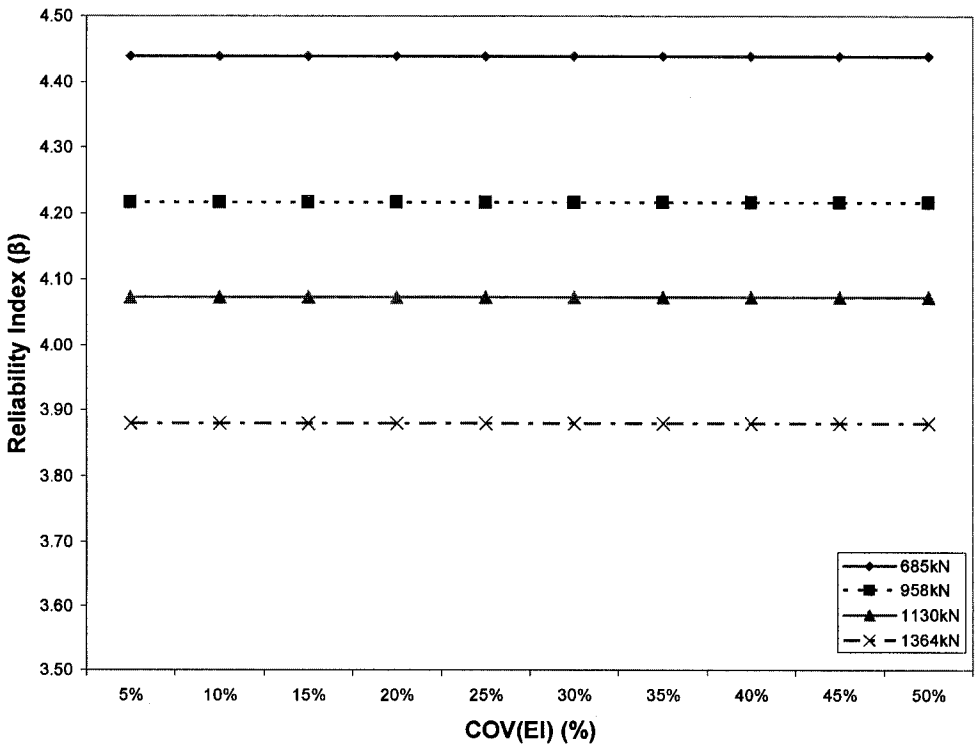

Fig. K.30 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'EI'.

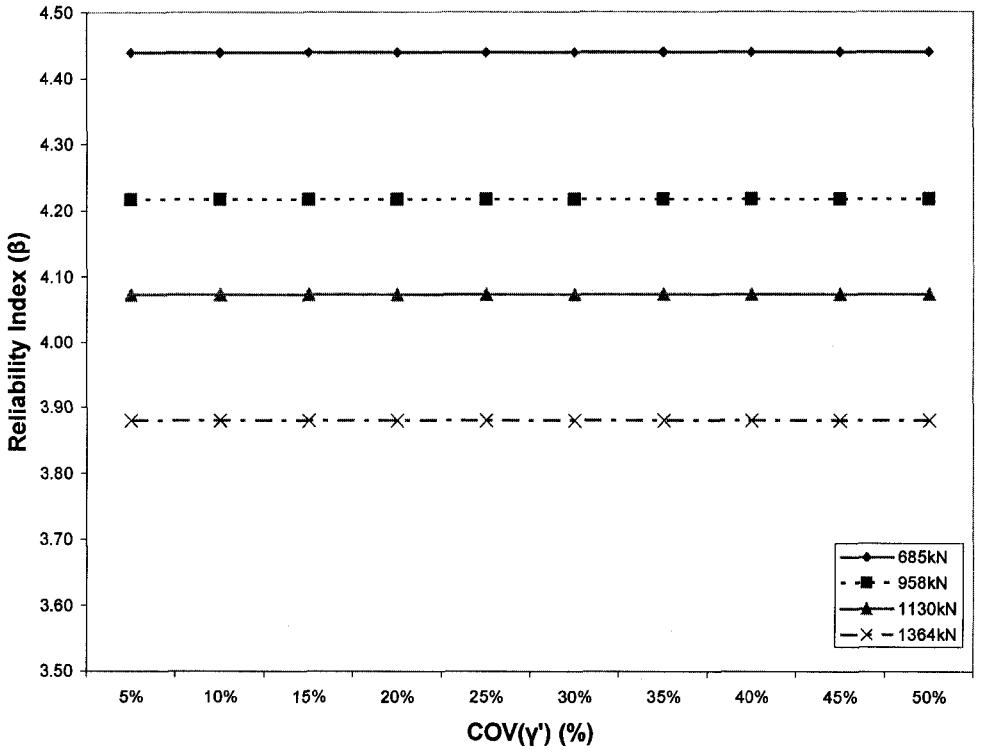

Fig. K.31 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'γ'.

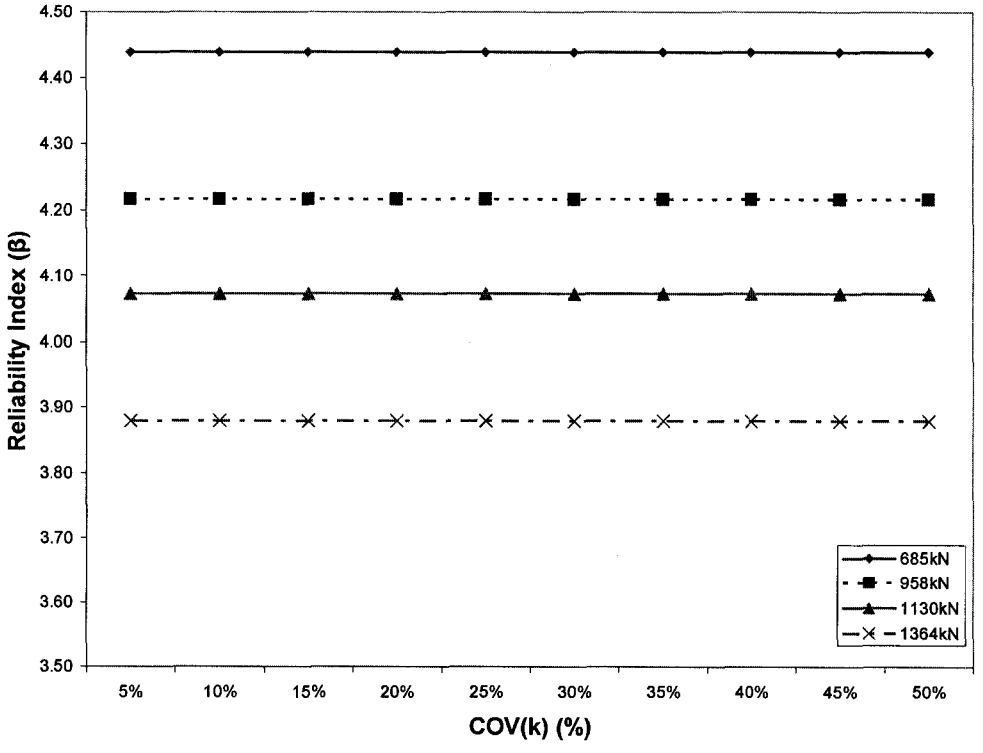

Fig. K.32 Reliability Index related to M_{Max} for leading row (Pile C) in hinged head long (10T) pile group with spacing (5D) and with varying 'k'.

APPENDIX L

LATERALLY LOADED FIXED HEAD LONG PILE

(Spacing: 5D)

L.1.1 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (5D) and with 'B' as varying random design variable

Table L.1. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1907 kN and 2356 kN.

			P=1907 kN (200, 210, 220 kN)				P=2356 kN (250, 260, 270 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45%	0.052258	0.2794	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
40%	0.0412902	0.3048	0.00445	81.93	83.12	84.39	0.00691	116.7	119.1	121.3
35%	0.0316128	0.3302	0.00418	79.26	80.34	81.5	0.00634	111.3	113.4	115.3
30%	0.0232258	0.3556	0.00403	78.28	79.29	80.4	0.00598	108.2	110.1	112.1
25%	0.016129	0.381	0.00391	77.55	78.53	79.6	0.00573	106.3	108.1	110
20%	0.0103226	0.4064	0.00383	77.11	78.05	79.08	0.00551	104.5	106.3	108.1
15%	0.0058064	0.4318	0.00374	76.66	77.55	78.52	0.00535	103.5	105.2	106.9
10%	0.0025806	0.4572	0.00367	76.28	77.12	78.05	0.0052	102.4	104	105.7
5%	0.0006452	0.4826	0.0036	75.97	76.75	77.86	0.00508	101.7	103.3	104.9
0%	0	0.508	0.00354	75.74	76.48	78.12	0.005	101.4	102.9	104.5
5%	0.0006452	0.5334	0.00349	75.54	76.26	78.44	0.00491	101	102.5	104
10%	0.0025806	0.5588	0.00345	75.37	76.05	78.8	0.00483	100.6	102	103.5
15%	0.0058064	0.5842	0.0034	75.21	76.05	79.18	0.00476	100.3	101.7	103.1
20%	0.0103226	0.6096	0.00336	75.06	76.46	79.59	0.0047	100	101.3	102.6
25%	0.016129	0.635	0.00334	75.08	76.6	79.73	0.00465	99.92	101.2	102.5
30%	0.0232258	0.6604	0.00334	75.54	76.12	79.16	0.00465	100.5	101.8	103.1
35%	0.0316128	0.6858	0.00334	76	76.59	78.65	0.00464	101	102.2	103.6
40%	0.0412902	0.7112	0.00334	76.46	77.07	78.21	0.00464	101.4	102.7	104
45%	0.052258	0.7366	#	#	#	#	#	#	#	#
50%	0.064516	0.762	#	#	#	#	#	#	#	#

Table L.2 Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 2634 kN and 2943 kN.

			P=2634 kN (280, 290, 300 kN)				P=2943 kN (320, 330, 340 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(B) (%)	Var (B) (m)2	Bcurrent (m)	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.064516	0.254	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45%	0.052258	0.2794	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
40%	0.0412902	0.3048	0.00919	143.2	147.2	151	Failed	Failed	Failed	Failed
35%	0.0316128	0.3302	0.00812	134.2	137.4	140.4	0.0115	166.6	172.2	177.4
30%	0.0232258	0.3556	0.00755	129.6	132.5	135.2	0.00988	156.6	161.3	165.5
25%	0.016129	0.381	0.00714	126.5	129.1	131.5	0.00912	151.4	155.3	159
20%	0.0103226	0.4064	0.00682	124.1	126.4	128.7	0.00859	147.6	151.2	154.6
15%	0.0058064	0.4318	0.00657	122.3	124.5	126.7	0.00817	144.6	147.9	151
10%	0.0025806	0.4572	0.00635	120.6	122.7	124.9	0.00784	142.3	145.4	148.1
5%	0.0006452	0.4826	0.00616	119.2	121.3	123.4	0.00757	140.5	143.2	145.9
0%	0	0.508	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
5%	0.0006452	0.5334	0.0059	117.7	119.6	121.6	0.00718	137.9	140.5	143
10%	0.0025806	0.5588	0.0058	117.2	119	121	0.00701	136.8	139.3	141.8
15%	0.0058064	0.5842	0.0057	116.7	118.5	120.4	0.00687	135.9	138.3	140.7
20%	0.0103226	0.6096	0.00561	116.2	118	119.9	0.00676	135.3	137.6	140
25%	0.016129	0.635	0.00555	116.1	117.8	119.6	0.00667	135	137.3	139.5
30%	0.0232258	0.6604	0.00554	116.6	118.4	120.1	0.00665	135.5	137.7	140
35%	0.0316128	0.6858	0.00553	117.1	118.8	120.6	0.00663	135.9	138.2	140.5
40%	0.0412902	0.7112	0.00554	117.7	119.5	121.3	#	#	#	#
45%	0.052258	0.7366	#	#	#	#	#	#	#	#
50%	0.064516	0.762	#	#	#	#	#	#	#	#

Table L.3(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1907 kN and 2356 kN.

		P=1907 kN		P=2356 kN	
COV(B) (%)	Var (B) (m)2	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.00064516	3.02E-09	1.554%	7.23E-09	1.700%
10%	0.00258064	1.21E-08	3.107%	3.42E-08	3.700%
15%	0.00580644	2.89E-08	4.802%	8.70E-08	5.900%
20%	0.01032256	5.52E-08	6.638%	1.64E-07	8.100%
25%	0.016129	8.12E-08	8.051%	2.92E-07	10.800%
30%	0.02322576	1.19E-07	9.746%	4.42E-07	13.300%
35%	0.03161284	1.76E-07	11.864%	7.23E-07	17.000%
40%	0.04129024	3.08E-07	15.678%	1.29E-06	22.700%

Table L.3(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (5D) and with varying 'B' and lateral load 2634 kN and 2943 kN.

		P=2634 kN		P=2943 kN	
COV(B) (%)	Var (B) (m)2	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.00064516	1.69E-08	2.156%	3.80E-08	2.646%
10%	0.00258064	7.56E-08	4.561%	1.72E-07	5.631%
15%	0.00580644	1.89E-07	7.214%	4.23E-07	8.820%
20%	0.01032256	3.66E-07	10.033%	8.37E-07	12.415%
25%	0.016129	6.32E-07	13.184%	1.50E-06	16.621%
30%	0.02322576	1.01E-06	16.667%	2.61E-06	21.913%
35%	0.03161284	1.68E-06	21.476%	5.93E-06	33.039%
40%	0.04129024	3.33E-06	30.265%	Failed	Failed

Table L.4(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 1907 kN.

		P=1907 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.00064516	0.046225	0.060025	0.0841	0.28%	0.32%	0.37%
10%	0.00258064	0.207025	0.286225	0.140625	0.60%	0.70%	0.48%
15%	0.00580644	0.525625	0.5625	0.1089	0.96%	0.98%	0.42%
20%	0.01032256	1.050625	0.632025	0.065025	1.35%	1.04%	0.33%
25%	0.016129	1.525225	0.931225	0.00169	1.63%	1.26%	0.05%
30%	0.02322576	1.8769	2.512225	0.3844	1.81%	2.07%	0.79%
35%	0.03161284	2.6569	3.515625	2.030625	2.15%	2.45%	1.82%
40%	0.04129024	7.480225	9.150625	9.5481	3.61%	3.96%	3.96%

Table L.4(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 2356 kN.

		P=2356 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.00064516	0.1225	0.16	0.2025	0.35%	0.39%	0.43%
10%	0.00258064	0.81	1	1.21	0.89%	0.97%	1.05%
15%	0.00580644	2.56	3.0625	3.61	1.58%	1.70%	1.82%
20%	0.01032256	5.0625	6.25	7.5625	2.22%	2.43%	2.63%
25%	0.016129	10.1761	11.9025	14.0625	3.15%	3.35%	3.59%
30%	0.02322576	14.8225	17.2225	20.25	3.80%	4.03%	4.31%
35%	0.03161284	26.5225	31.36	34.2225	5.08%	5.44%	5.60%
40%	0.04129024	58.5225	67.24	74.8225	7.54%	7.97%	8.28%

Table L.4(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 2634 kN.

		P=2634 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.00064516	0.5625	0.7225	0.81	0.63%	0.71%	0.74%
10%	0.00258064	2.89	3.4225	3.8025	1.44%	1.54%	1.59%
15%	0.00580644	7.84	9	9.9225	2.36%	2.49%	2.57%
20%	0.01032256	15.6025	17.64	19.36	3.34%	3.49%	3.59%
25%	0.016129	27.04	31.9225	35.4025	4.39%	4.69%	4.86%
30%	0.02322576	42.25	49.7025	57.0025	5.49%	5.86%	6.17%
35%	0.03161284	73.1025	86.49	98.01	7.22%	7.72%	8.09%
40%	0.04129024	162.5625	191.8225	220.5225	10.77%	11.50%	12.13%

Table L.4(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and lateral load 2943 kN.

		P=2943 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(B) (%)	Var (B) (m)2	A	B	C	A	B	C
5%	0.00064516	1.69	1.8225	2.1025	0.93%	0.95%	1.00%
10%	0.00258064	7.5625	9.3025	9.9225	1.98%	2.15%	2.18%
15%	0.00580644	18.9225	23.04	26.5225	3.13%	3.39%	3.57%
20%	0.01032256	37.8225	46.24	53.29	4.42%	4.80%	5.06%
25%	0.016129	67.24	81	95.0625	5.89%	6.35%	6.75%
30%	0.02322576	111.3025	139.24	162.5625	7.58%	8.32%	8.83%
35%	0.03161284	235.6225	289	340.4025	11.03%	11.99%	12.78%
40%	0.04129024	Failed	Failed	Failed	Failed	Failed	Failed

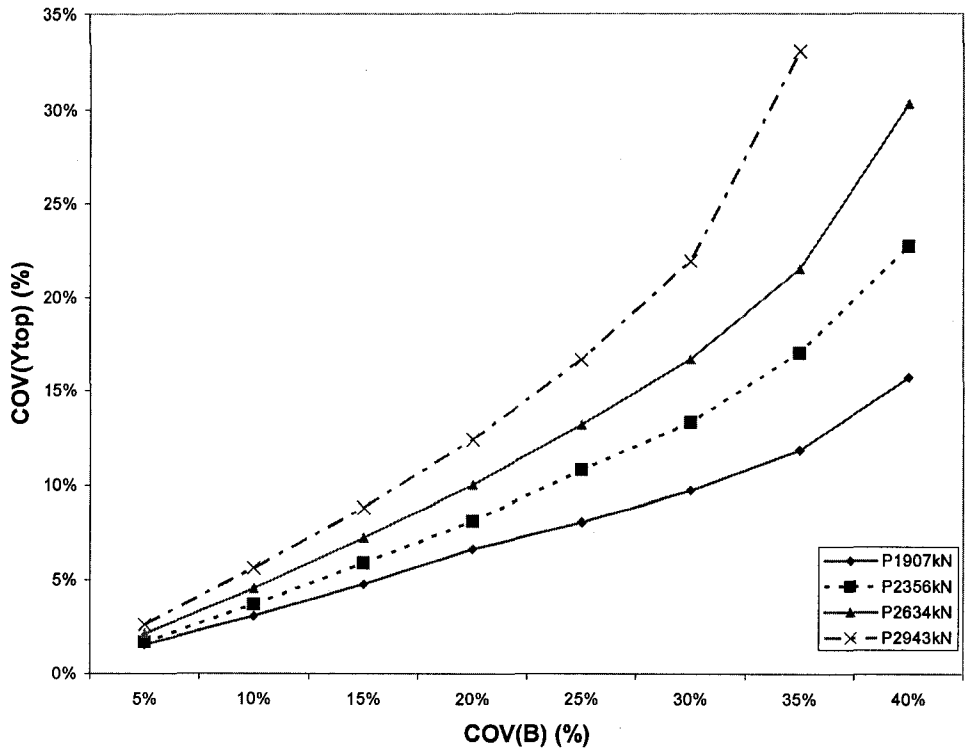

Fig. L.1 COV(Y_{Top}) for varying COV(B) in fixed head long (10T) pile group with spacing (5D).

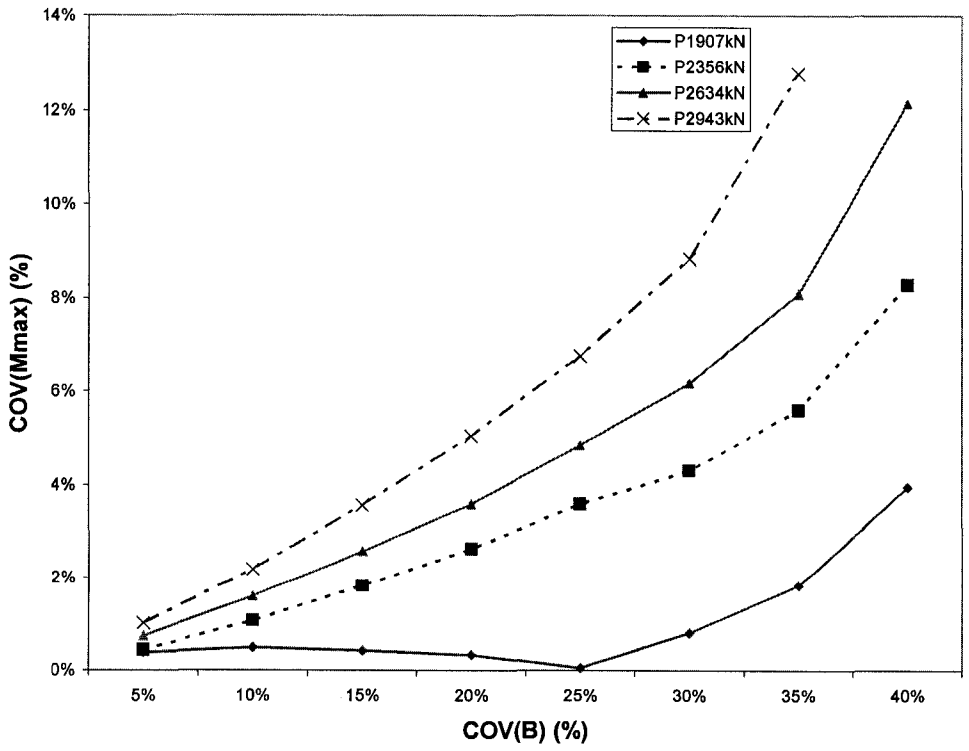

Fig. L.2(a) COV(M_{Max}) for varying COV(B) for pile C in fixed head long pile group with spacing (5D).

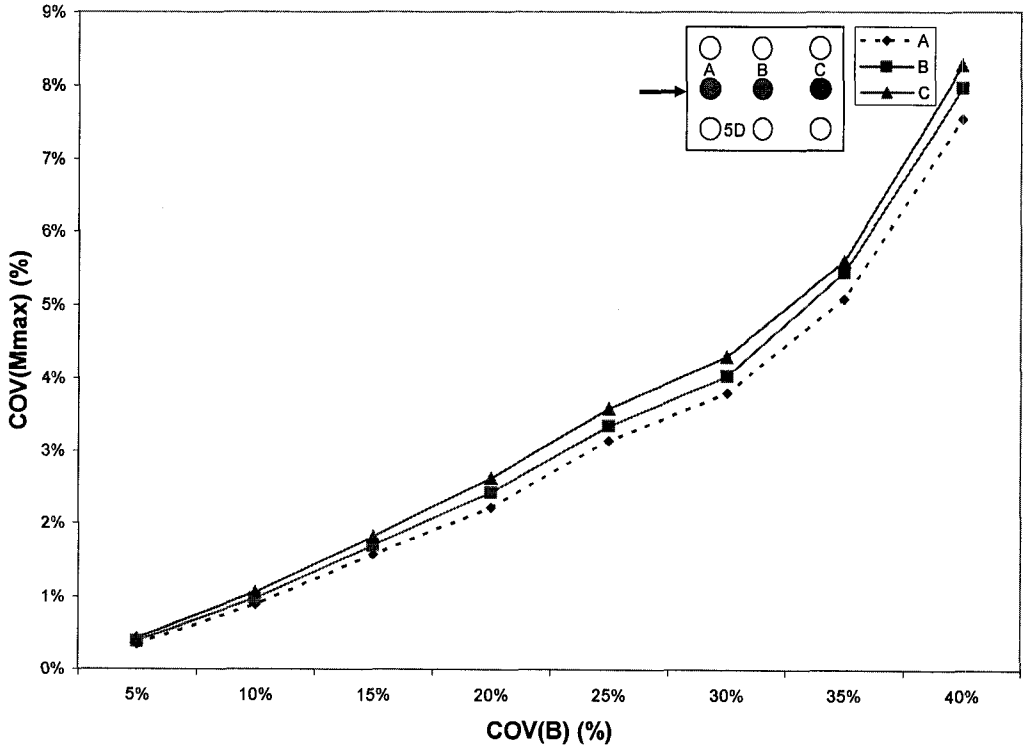

Fig. L.2(b) COV(M_{Max}) for varying COV(B) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (5D) at the optimum lateral load 2356 kN.

L.1.2 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (5D) and with 'C' as varying random design variable

Table L.5. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1907 kN and 2356 kN.

			P=1907 kN (200, 210, 220 kN)				P=2356 kN (250, 260, 270 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45.00%	1139.0625	41.25	0.00667	95.03	98.24	101.3	0.0102	122.3	127.2	132
40.00%	900	45	0.00601	93.42	96.23	98.91	0.00901	121.7	126	130.2
35.00%	689.0625	48.75	0.00548	91.44	93.87	96.2	0.00813	119.9	123.8	127.5
30.00%	506.25	52.5	0.00506	89.34	91.4	93.38	0.00743	117.7	121.2	124.5
25.00%	351.5625	56.25	0.00471	87.2	88.89	90.51	0.00682	115.2	118.2	121.1
20.00%	225	60	0.00443	84.9	86.35	87.85	0.00633	112.5	115.1	117.6
15.00%	126.5625	63.75	0.00417	82.5	83.8	85.15	0.0059	109.6	111.8	113.8
10.00%	56.25	67.5	0.00394	80.2	81.32	82.53	0.00556	106.8	108.7	110.6
5.00%	14.0625	71.25	0.00373	77.96	78.9	79.92	0.00526	104	105.7	107.4
0.00%	0	75	0.00354	75.74	76.48	78.12	0.005	101.4	102.9	104.5
5.00%	14.0625	78.75	0.00338	73.55	75.81	78.87	0.00476	98.79	100.1	101.4
10.00%	56.25	82.5	0.00323	73.48	76.49	79.45	0.00452	96.11	97.16	98.33
15.00%	126.5625	86.25	0.00309	74.12	77.02	79.89	0.00432	93.56	94.42	98.17
20.00%	225	90	0.00297	74.64	77.42	80.19	0.00414	91.26	95.12	98.88
25.00%	351.5625	93.75	0.00286	75.09	77.69	80.29	0.00397	92.03	95.77	99.44
30.00%	506.25	97.5	0.00277	75.39	77.89	80.46	0.00382	92.66	96.28	99.83
35.00%	689.0625	101.25	0.00269	75.61	78.07	80.61	0.00369	93.18	96.67	100
40.00%	900	105	0.00261	75.8	78.2	80.71	0.00357	93.55	96.84	100.1
45.00%	1139.0625	108.75	0.00253	75.94	78.29	80.76	0.00346	93.77	96.91	100.1
50.00%	1406.25	112.5	#	#	#	#	#	#	#	#

Table L.6. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 2634 kN and 2943 kN.

			P=2634 kN (280, 290, 300 kN)				P=2943 kN (320, 330, 340 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(C) (%)	Var (C) $(kPa)^2$	Ccurrent (kPa)	A/B/C	A	B	C	A/B/C	A	B	C
50.00%	1406.25	37.5	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
45.00%	1139.0625	41.25	0.0134	152.1	154.9	157.4	0.0197	200.2	206.4	211.9
40.00%	900	45	0.0115	138.7	144.5	149.9	0.0157	178.4	181.9	185
35.00%	689.0625	48.75	0.0102	138	143.3	148.2	0.0134	160.8	164.7	171
30.00%	506.25	52.5	0.00923	136.2	140.7	144.9	0.0118	157	163.2	169
25.00%	351.5625	56.25	0.00845	133.7	137.7	141.5	0.0107	155.3	160.9	165.9
20.00%	225	60	0.00779	130.9	134.4	137.7	0.00975	152.7	157.4	161.8
15.00%	126.5625	63.75	0.00725	128	131.1	134	0.00899	149.4	153.6	157.5
10.00%	56.25	67.5	0.00677	124.9	127.5	129.9	0.00836	146	149.7	153.2
5.00%	14.0625	71.25	0.00637	121.6	123.8	126	0.00782	142.6	145.8	148.6
0.00%	0	75	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
5.00%	14.0625	78.75	0.00572	115.4	117.1	119	0.00696	135.4	137.8	140.3
10.00%	56.25	82.5	0.00544	112.5	114.1	115.7	0.0066	131.9	134.1	136.3
15.00%	126.5625	86.25	0.00519	109.7	111	112.4	0.00627	128.5	130.4	132.4
20.00%	225	90	0.00497	106.9	108	110.1	0.006	125.5	127.2	128.8
25.00%	351.5625	93.75	0.00477	104.2	106.7	111	0.00574	122.5	123.9	125.4
30.00%	506.25	97.5	0.00458	103.1	107.4	111.6	0.00552	119.5	120.7	124.5
35.00%	689.0625	101.25	0.00441	103.9	108	112.1	0.0053	116.6	120.5	125.3
40.00%	900	105	0.00425	104.5	108.5	112.5	0.0051	116.4	121.2	125.9
45.00%	1139.0625	108.75	0.00411	105	108.9	112.5	0.00492	117.1	121.8	126.3
50.00%	1406.25	112.5	#	#	#	#	#	#	#	#

Table L.7(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1907 kN and 2356 kN.

		P=1907 kN		P=2356 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	14.0625	3.06E-08	4.944%	6.25E-08	5.000%
10.00%	56.25	1.26E-07	10.028%	2.70E-07	10.400%
15.00%	126.5625	2.92E-07	15.254%	6.24E-07	15.800%
20.00%	225	5.33E-07	20.621%	1.20E-06	21.900%
25.00%	351.5625	8.56E-07	26.130%	2.03E-06	28.500%
30.00%	506.25	1.31E-06	32.345%	3.26E-06	36.100%
35.00%	689.0625	1.95E-06	39.407%	4.93E-06	44.400%
40.00%	900	2.89E-06	48.023%	7.40E-06	54.400%
45.00%	1139.0625	4.28E-06	58.475%	1.14E-05	67.400%

Table L.7(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (5D) and with varying 'C' and lateral load 2634 kN and 2943 kN.

		P=2634 kN		P=2943 kN	
COV(C) (%)	Var (C) $(kPa)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5.00%	14.0625	1.06E-07	5.390%	1.85E-07	5.834%
10.00%	56.25	4.42E-07	11.028%	7.74E-07	11.940%
15.00%	126.5625	1.06E-06	17.081%	1.85E-06	18.453%
20.00%	225	1.99E-06	23.383%	3.52E-06	25.441%
25.00%	351.5625	3.39E-06	30.514%	6.15E-06	33.650%
30.00%	506.25	5.41E-06	38.557%	9.86E-06	42.605%
35.00%	689.0625	8.38E-06	48.010%	1.64E-05	54.953%
40.00%	900	1.31E-05	60.116%	2.81E-05	71.913%
45.00%	1139.0625	2.16E-05	77.032%	5.46E-05	100.271%

Table L.8(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 1907 kN.

		P=1907 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	4.862025	2.387025	0.275625	2.91%	2.02%	0.67%
10.00%	56.25	11.2896	5.832225	2.3716	4.44%	3.16%	1.97%
15.00%	126.5625	17.5561	11.4921	6.9169	5.53%	4.43%	3.37%
20.00%	225	26.3169	19.936225	14.6689	6.77%	5.84%	4.90%
25.00%	351.5625	36.663025	31.36	10.44484	7.99%	7.32%	4.14%
30.00%	506.25	48.650625	45.630025	41.7316	9.21%	8.83%	8.27%
35.00%	689.0625	62.647225	62.41	60.762025	10.45%	10.33%	9.98%
40.00%	900	77.6161	81.270225	82.81	11.63%	11.79%	11.65%
45.00%	1139.0625	91.107025	99.500625	105.4729	12.60%	13.04%	13.15%

Table L.8(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 2356 kN.

		P=2356 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	6.786025	7.84	9	2.57%	2.72%	2.87%
10.00%	56.25	28.569025	33.2929	37.638225	5.27%	5.61%	5.87%
15.00%	126.5625	64.3204	75.5161	61.074225	7.91%	8.45%	7.48%
20.00%	225	112.7844	99.8001	87.6096	10.47%	9.71%	8.96%
25.00%	351.5625	134.21223	125.77623	117.2889	11.43%	10.90%	10.36%
30.00%	506.25	156.7504	155.2516	152.15223	12.35%	12.11%	11.80%
35.00%	689.0625	178.4896	184.00923	189.0625	13.18%	13.18%	13.16%
40.00%	900	198.10563	212.5764	226.5025	13.88%	14.17%	14.40%
45.00%	1139.0625	203.49023	229.37103	254.4025	14.07%	14.72%	15.26%

Table L.8(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 2634 kN.

		P=2634 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	9.61	11.2225	12.25	2.62%	2.78%	2.86%
10.00%	56.25	38.44	44.89	50.41	5.24%	5.56%	5.80%
15.00%	126.5625	83.7225	101.0025	116.64	7.73%	8.35%	8.82%
20.00%	225	144	174.24	190.44	10.14%	10.96%	11.27%
25.00%	351.5625	217.5625	240.25	232.5625	12.46%	12.87%	12.46%
30.00%	506.25	273.9025	277.2225	277.2225	13.98%	13.83%	13.60%
35.00%	689.0625	290.7025	311.5225	325.8025	14.40%	14.66%	14.75%
40.00%	900	292.41	324	349.69	14.44%	14.95%	15.28%
45.00%	1139.0625	554.6025	529	504.0025	19.89%	19.10%	18.34%

Table L.8(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'C' and lateral load 2943 kN.

		P=2943 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(C) (%)	Var (C) (kPa)^2	A	B	C	A	B	C
5.00%	14.0625	12.96	16	17.2225	2.59%	2.82%	2.87%
10.00%	56.25	49.7025	60.84	71.4025	5.06%	5.50%	5.85%
15.00%	126.5625	109.2025	134.56	157.5025	7.51%	8.18%	8.69%
20.00%	225	184.96	228.01	272.25	9.77%	10.65%	11.43%
25.00%	351.5625	268.96	342.25	410.0625	11.78%	13.05%	14.02%
30.00%	506.25	351.5625	451.5625	495.0625	13.47%	14.99%	15.41%
35.00%	689.0625	488.41	488.41	522.1225	15.88%	15.59%	15.82%
40.00%	900	961	921.1225	873.2025	22.27%	21.40%	20.46%
45.00%	1139.0625	1726.4025	1789.29	1831.84	29.85%	29.83%	29.64%

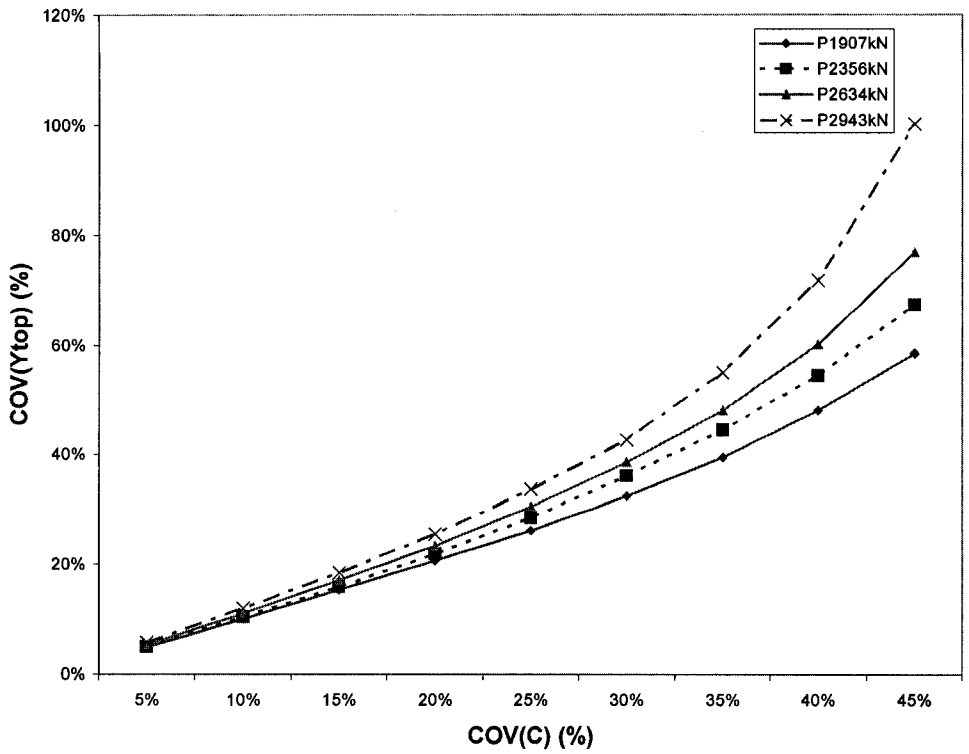

Fig. L.3 COV(Y_{Top}) for varying COV(C) in fixed head long (10T) pile group with spacing (5D).

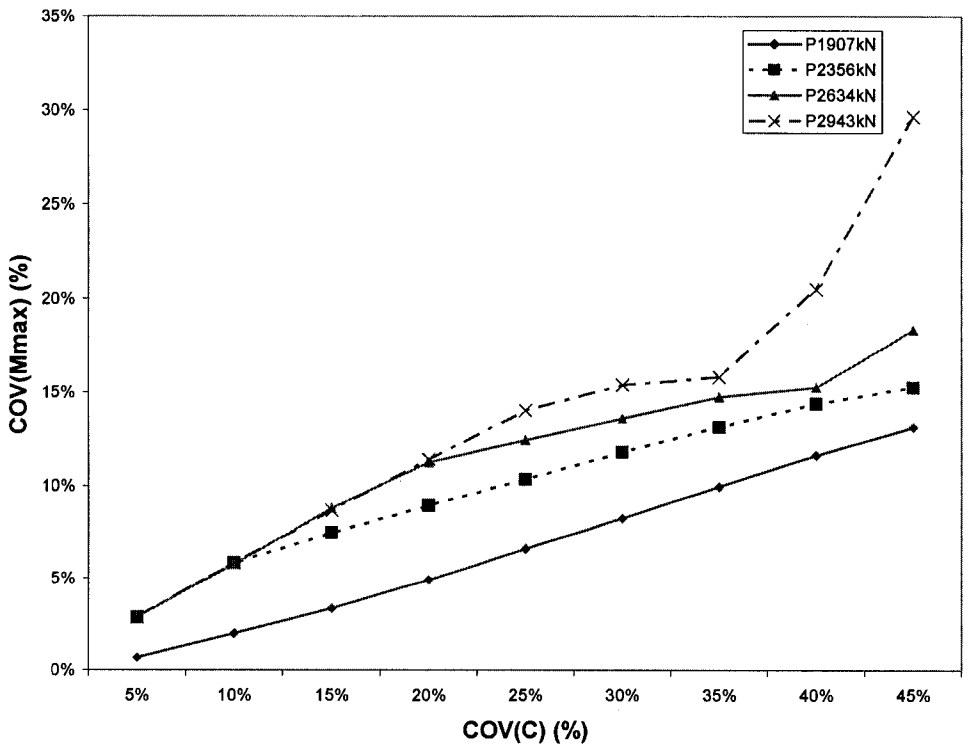

Fig. L.4(a) COV(M_{Max}) for varying COV(C) for pile C in fixed head long pile group with spacing (5D).

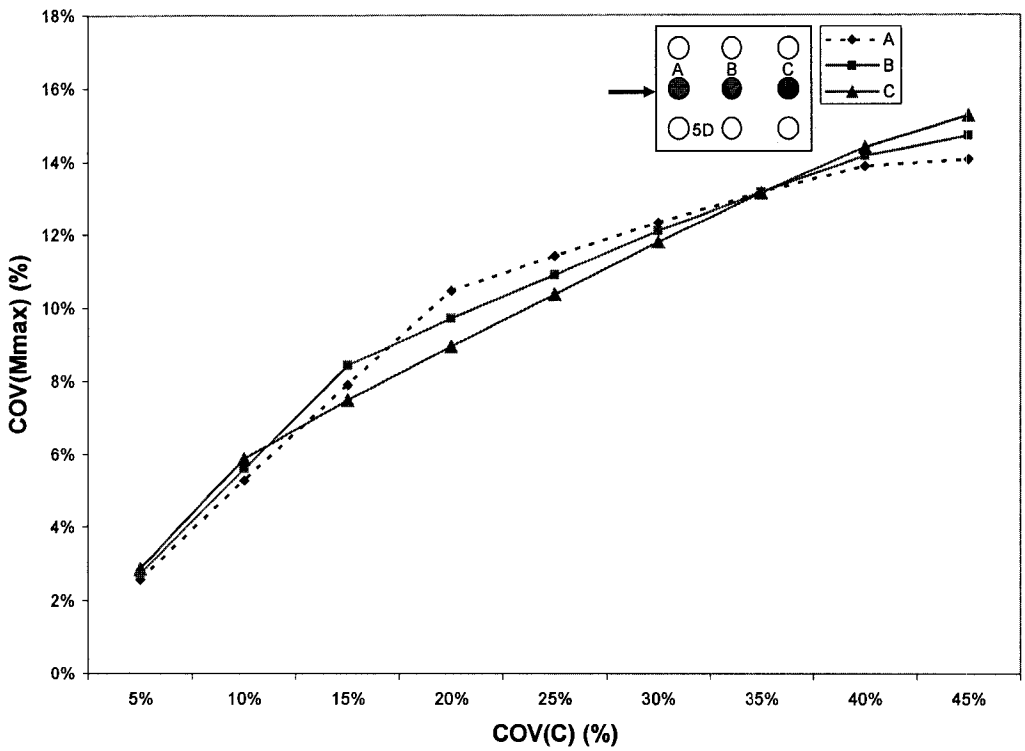

Fig. L.4(b) COV(M_{Max}) for varying COV(C) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (5D) at the optimum lateral load 2356 kN.

L.1.3 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (5D) and with 'ε_{50}' as varying random design variable

Table L.9. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1907 kN and 2356 kN.

			P=1907 kN (200, 210, 220 kN)				P=2356 kN (250, 260, 270 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00273	78.02	80.59	83.23	0.00389	97.71	101.7	105.3
45%	9.9225E-06	0.00385	0.00282	77.44	80.05	82.72	0.00401	96.45	100.4	104.1
40%	0.00000784	0.0042	0.00291	76.94	79.54	82.22	0.00414	95.24	99.25	103.1
35%	6.0025E-06	0.00455	0.00299	76.28	79.09	81.81	0.00425	94.29	98.01	101.9
30%	0.00000441	0.0049	0.00307	75.62	78.52	81.4	0.00436	95.51	96.86	100.8
25%	3.0625E-06	0.00525	0.00315	74.98	77.95	80.89	0.00448	96.84	97.81	99.71
20%	0.00000196	0.0056	0.00323	74.34	77.37	80.36	0.00459	97.9	98.98	100.2
15%	1.1025E-06	0.00595	0.00331	73.71	76.79	79.81	0.00468	98.75	99.95	101.2
10%	0.00000049	0.0063	0.0034	74.02	76.13	79.2	0.00478	99.65	101	102.4
5%	1.225E-07	0.00665	0.00347	74.91	75.57	78.66	0.00488	100.5	101.9	103.4
0%	0	0.007	0.00354	75.74	76.48	78.12	0.005	101.4	102.9	104.5
5%	1.225E-07	0.00735	0.00361	76.51	77.33	78.26	0.00509	102.1	103.7	105.3
10%	0.00000049	0.0077	0.00368	77.22	78.13	79.12	0.00519	102.8	104.4	106.1
15%	1.1025E-06	0.00805	0.00375	77.89	78.87	79.92	0.00527	103.5	105.2	106.9
20%	0.00000196	0.0084	0.00382	78.52	79.56	80.68	0.00536	104.1	105.8	107.6
25%	3.0625E-06	0.00875	0.00388	79.12	80.21	81.39	0.00545	104.7	106.5	108.3
30%	0.00000441	0.0091	0.00395	79.69	80.84	82.06	0.00553	105.2	107.1	109
35%	6.0025E-06	0.00945	0.00401	80.23	81.43	82.69	0.00562	105.8	107.7	109.6
40%	0.00000784	0.0098	0.00407	80.74	81.99	83.3	0.0057	106.3	108.2	110.2
45%	9.9225E-06	0.01015	0.00413	81.24	82.53	83.88	0.00576	106.7	108.7	110.7
50%	0.00001225	0.0105	0.00419	81.72	83.04	84.43	0.00584	107.1	109.2	111.2

Table L.10. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 2634 kN and 2943 kN.

			P=2634 kN (280, 290, 300 kN)				P=2943 kN (320, 330, 340 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(ε_{50}) (%)	Var (ε_{50})	ε_{50} current	A/B/C	A	B	C	A/B/C	A	B	C
50%	0.00001225	0.0035	0.00481	108.9	113	117.8	0.00609	133.7	135.3	136.9
45%	9.9225E-06	0.00385	0.00494	110.1	111.4	116.2	0.00622	134.2	136	137.8
40%	0.00000784	0.0042	0.00509	111.5	112.7	114.6	0.00636	134.8	136.8	138.8
35%	6.0025E-06	0.00455	0.0052	112.5	113.7	115.1	0.00649	135.2	137.3	139.4
30%	0.00000441	0.0049	0.00532	113.5	114.9	116.4	0.00661	135.8	138	140.2
25%	3.0625E-06	0.00525	0.00546	114.6	116.2	117.8	0.00676	136.5	138.8	141.1
20%	0.00000196	0.0056	0.00558	115.4	117.1	118.8	0.00688	137	139.4	141.8
15%	1.1025E-06	0.00595	0.00569	116.2	118	119.8	0.007	137.5	139.9	142.4
10%	0.00000049	0.0063	0.0058	116.9	118.8	120.7	0.00714	138.2	140.7	143.2
5%	1.225E-07	0.00665	0.00593	117.8	119.7	121.7	0.00725	138.7	141.2	143.8
0%	0	0.007	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
5%	1.225E-07	0.00735	0.00613	119	121.1	123.2	0.00748	139.6	142.3	145
10%	0.00000049	0.0077	0.00623	119.6	121.8	123.9	0.00759	139.9	142.9	145.5
15%	1.1025E-06	0.00805	0.00633	120.3	122.4	124.6	0.00771	140.2	143.3	146.1
20%	0.00000196	0.0084	0.00643	120.8	123.1	125.3	0.00782	140.5	143.7	146.7
25%	3.0625E-06	0.00875	0.00653	121.4	123.7	125.9	0.00793	140.8	144.1	147.2
30%	0.00000441	0.0091	0.00663	121.8	124.3	126.6	0.00804	141	144.5	147.7
35%	6.0025E-06	0.00945	0.00673	122.2	124.8	127.2	0.00814	141.3	144.8	148.1
40%	0.00000784	0.0098	0.00682	122.6	125.3	127.8	0.00825	141.5	145.1	148.4
45%	9.9225E-06	0.01015	0.00691	122.9	125.7	128.4	0.00836	141.6	145.3	148.8
50%	0.00001225	0.0105	0.00701	123.3	126.1	128.8	0.00846	141.8	145.6	149.1

Table L.11(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1907 kN and 2356 kN.

		P=1907 kN		P=2356 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	4.90E-09	1.977%	1.10E-08	2.100%
10%	4.90E-07	1.96E-08	3.955%	4.20E-08	4.100%
15%	1.10E-06	4.84E-08	6.215%	8.70E-08	5.900%
20%	1.96E-06	8.70E-08	8.333%	1.48E-07	7.700%
25%	3.06E-06	1.33E-07	10.311%	2.35E-07	9.700%
30%	4.41E-06	1.94E-07	12.429%	3.42E-07	11.700%
35%	6.00E-06	2.60E-07	14.407%	4.69E-07	13.700%
40%	7.84E-06	3.36E-07	16.384%	6.08E-07	15.600%
45%	9.92E-06	4.29E-07	18.503%	7.66E-07	17.500%
50%	1.23E-05	5.33E-07	20.621%	9.51E-07	19.500%

Table L.11(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 2634 kN and 2943 kN.

		P=2634 kN		P=2943 kN	
COV(ε_{50}) (%)	Var (ε_{50})	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	1.23E-07	1.00E-08	1.658%	1.32E-08	1.560%
10%	4.90E-07	4.62E-08	3.566%	5.06E-08	3.053%
15%	1.10E-06	1.02E-07	5.307%	1.26E-07	4.817%
20%	1.96E-06	1.81E-07	7.048%	2.21E-07	6.377%
25%	3.06E-06	2.86E-07	8.872%	3.42E-07	7.938%
30%	4.41E-06	4.29E-07	10.862%	5.11E-07	9.701%
35%	6.00E-06	5.85E-07	12.687%	6.81E-07	11.194%
40%	7.84E-06	7.48E-07	14.345%	8.93E-07	12.822%
45%	9.92E-06	9.70E-07	16.335%	1.14E-06	14.518%
50%	1.23E-05	1.21E-06	18.242%	1.40E-06	16.079%

Table L.12(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 1907 kN.

		P=1907 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.64	0.7744	0.04	1.06%	1.15%	0.26%
10%	4.90E-07	2.56	1	0.0016	2.11%	1.31%	0.05%
15%	1.10E-06	4.3681	1.0816	0.003025	2.76%	1.36%	0.07%
20%	1.96E-06	4.3681	1.199025	0.0256	2.76%	1.43%	0.20%
25%	3.06E-06	4.2849	1.2769	0.025	2.73%	1.48%	0.20%
30%	4.41E-06	4.141225	1.3456	0.1089	2.69%	1.52%	0.42%
35%	6.00E-06	3.900625	1.3689	0.1936	2.61%	1.53%	0.56%
40%	7.84E-06	3.61	1.500625	0.2916	2.51%	1.60%	0.69%
45%	9.92E-06	3.61	1.5376	0.3364	2.51%	1.62%	0.74%
50%	1.23E-05	3.4225	1.500625	0.36	2.44%	1.60%	0.77%

Table L.12(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 2356 kN.

		P=2356 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.64	0.81	0.9025	0.79%	0.87%	0.91%
10%	4.90E-07	2.480625	2.89	3.4225	1.55%	1.65%	1.77%
15%	1.10E-06	5.640625	6.890625	8.1225	2.34%	2.55%	2.73%
20%	1.96E-06	9.61	11.6281	13.69	3.06%	3.31%	3.54%
25%	3.06E-06	15.4449	18.879025	18.447025	3.88%	4.22%	4.11%
30%	4.41E-06	23.474025	26.2144	16.81	4.78%	4.98%	3.92%
35%	6.00E-06	33.120025	23.474025	14.8225	5.68%	4.71%	3.68%
40%	7.84E-06	30.5809	20.025625	12.6025	5.45%	4.35%	3.40%
45%	9.92E-06	26.265625	17.2225	10.89	5.05%	4.03%	3.16%
50%	1.23E-05	22.043025	14.0625	8.7025	4.63%	3.64%	2.82%

Table L.12(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 2634 kN.

		P=2634 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.36	0.49	0.5625	0.51%	0.58%	0.61%
10%	4.90E-07	1.8225	2.25	2.56	1.14%	1.25%	1.31%
15%	1.10E-06	4.2025	4.84	5.76	1.73%	1.83%	1.96%
20%	1.96E-06	7.29	9	10.5625	2.28%	2.49%	2.66%
25%	3.06E-06	11.56	14.0625	16.4025	2.87%	3.11%	3.31%
30%	4.41E-06	17.2225	22.09	26.01	3.51%	3.90%	4.17%
35%	6.00E-06	23.5225	30.8025	36.6025	4.10%	4.61%	4.94%
40%	7.84E-06	30.8025	39.69	43.56	4.69%	5.23%	5.39%
45%	9.92E-06	40.96	51.1225	37.21	5.41%	5.94%	4.98%
50%	1.23E-05	51.84	42.9025	30.25	6.08%	5.44%	4.49%

Table L.12(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and lateral load 2943 kN.

		P=2943 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(ε_{50}) (%)	Var (ε_{50})	A	B	C	A	B	C
5%	1.23E-07	0.2025	0.3025	0.36	0.32%	0.39%	0.42%
10%	4.90E-07	0.7225	1.21	1.3225	0.61%	0.78%	0.80%
15%	1.10E-06	1.8225	2.89	3.4225	0.97%	1.20%	1.28%
20%	1.96E-06	3.0625	4.6225	6.0025	1.26%	1.52%	1.70%
25%	3.06E-06	4.6225	7.0225	9.3025	1.54%	1.87%	2.11%
30%	4.41E-06	6.76	10.5625	14.0625	1.87%	2.29%	2.60%
35%	6.00E-06	9.3025	14.0625	18.9225	2.19%	2.64%	3.01%
40%	7.84E-06	11.2225	17.2225	23.04	2.41%	2.93%	3.32%
45%	9.92E-06	13.69	21.6225	30.25	2.66%	3.28%	3.81%
50%	1.23E-05	16.4025	26.5225	37.21	2.91%	3.63%	4.22%

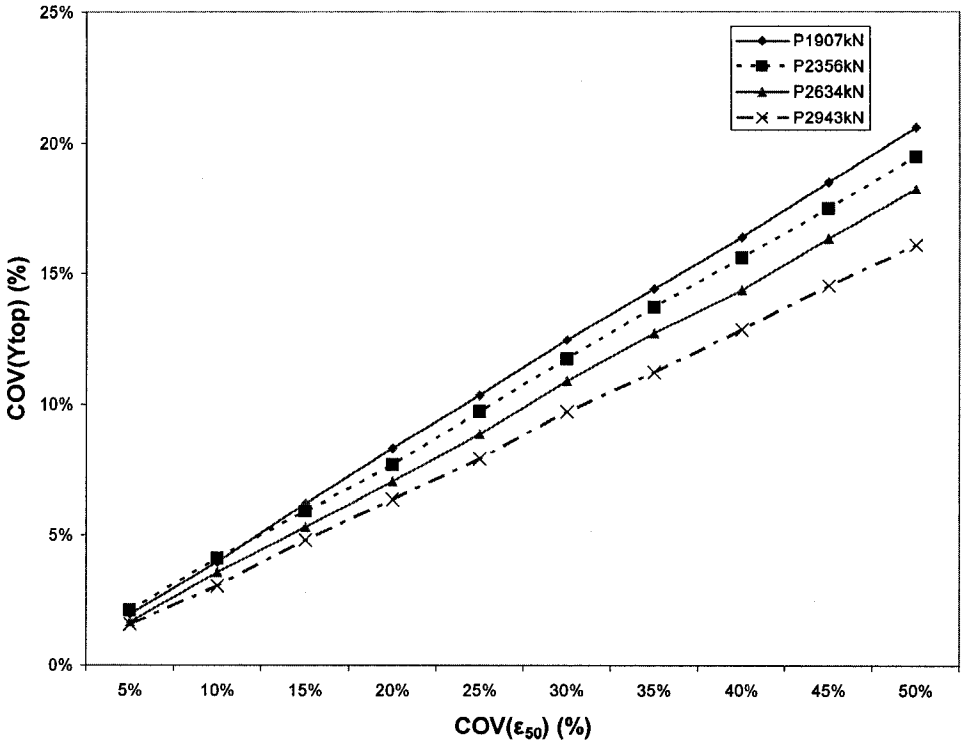

Fig. L.5 COV(Y_{Top}) for varying COV(ε_{50}) in fixed head long (10T) pile group with spacing (5D).

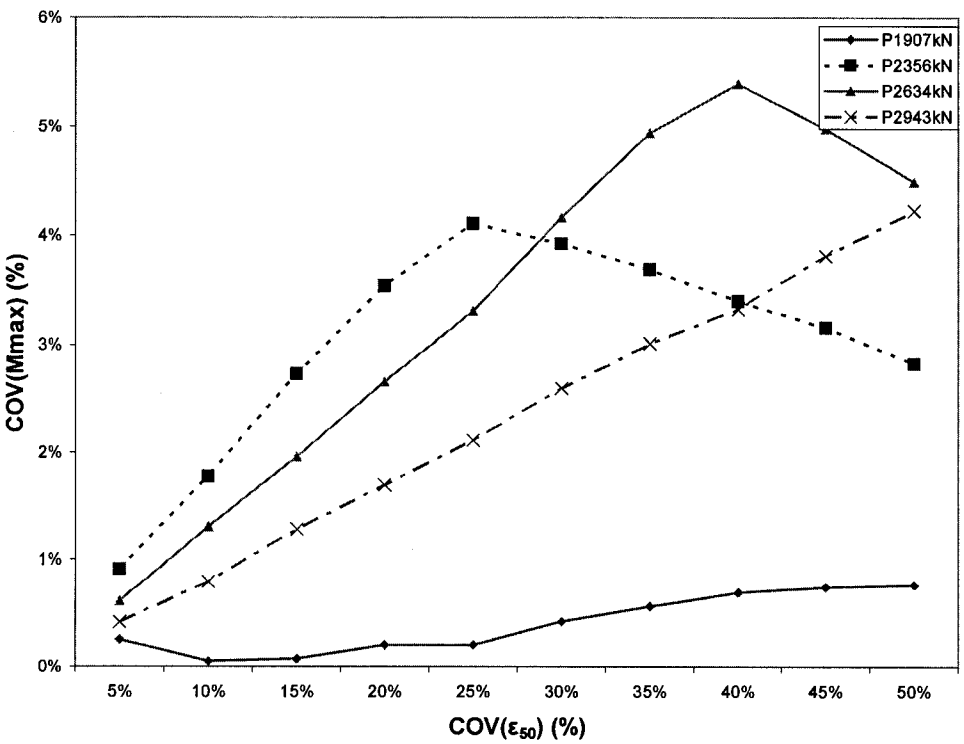

Fig. L.6(a) COV(M_{Max}) for varying COV(ε_{50}) for pile C in fixed head long pile group with spacing (5D).

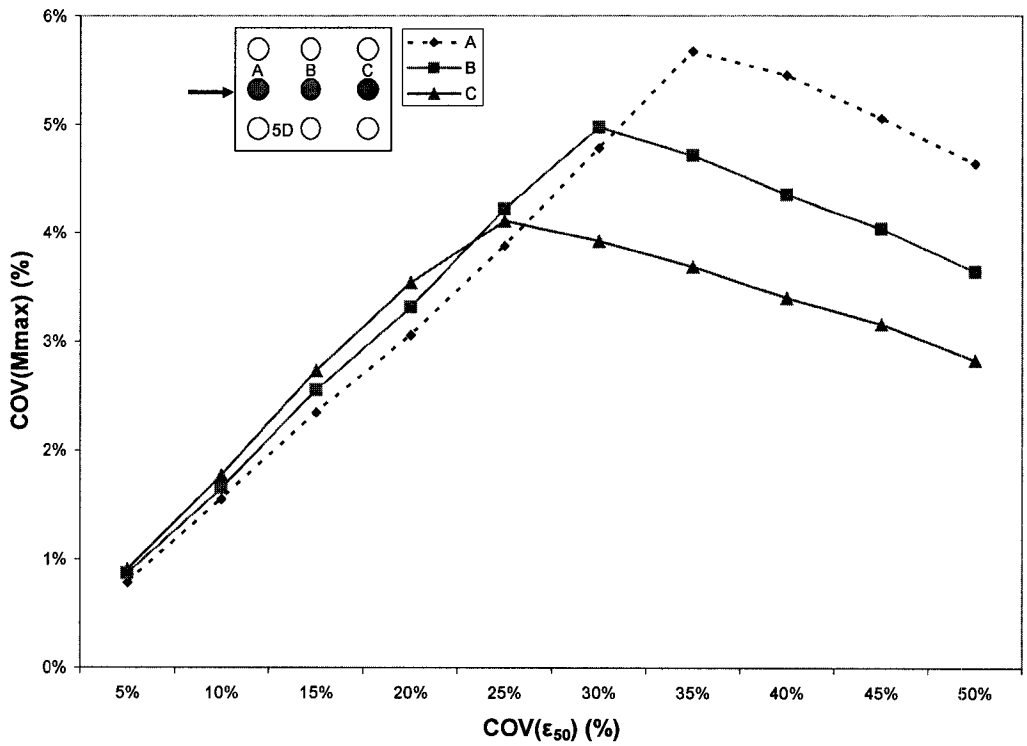

Fig. L.6(b) COV(M_{Max}) for varying COV(ε_{50}) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (5D) at the optimum lateral load 2356 kN.

L.1.4 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (5D) and with 'EI' as varying random design variable

Table L.13. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1907 kN and 2356 kN.

			P=1907 kN (200, 210, 220 kN)				P=2356 kN (250, 260, 270 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00514	74.94	77.71	80.35	0.00737	93.32	97.4	101.1
45%	2.45E+09	60500	0.00487	74.61	77.44	80.15	0.00695	92.54	96.57	100.3
40%	1.94E+09	66000	0.00463	74.29	77.17	79.94	0.00661	91.78	95.77	99.53
35%	1.48E+09	71500	0.00443	73.95	76.9	79.72	0.00631	92.24	95.05	98.87
30%	1.09E+09	77000	0.00425	73.65	76.62	79.49	0.00605	93.79	94.83	98.23
25%	7.56E+08	82500	0.0041	73.34	76.36	79.28	0.00582	95.19	96.34	97.61
20%	4.84E+08	88000	0.00396	73.04	76.1	79.06	0.00561	96.57	97.8	99.04
15%	2.72E+08	93500	0.00384	72.75	75.84	78.84	0.00544	97.94	99.24	100.6
10%	1.21E+08	99000	0.00374	73.61	75.52	78.57	0.00527	99.15	100.5	101.9
5%	3.03E+07	104500	0.00364	74.69	75.39	78.35	0.00512	100.2	101.6	103.1
0%	0.00E+00	110000	0.00354	75.74	76.48	78.12	0.005	101.4	102.9	104.5
5%	3.03E+07	115500	0.00346	76.74	77.54	78.45	0.00487	102.4	104	105.6
10%	1.21E+08	121000	0.00338	77.66	78.52	79.49	0.00476	103.4	105	106.7
15%	2.72E+08	126500	0.0033	78.55	79.46	80.49	0.00465	104.4	106	107.7
20%	4.84E+08	132000	0.00324	79.38	80.33	81.42	0.00455	105.2	106.9	108.7
25%	7.56E+08	137500	0.00317	80.21	81.21	82.35	0.00445	106.1	107.8	109.7
30%	1.09E+09	143000	0.00311	80.99	82.03	83.22	0.00437	106.9	108.7	110.6
35%	1.48E+09	148500	0.00306	81.74	82.82	84.06	0.00428	107.8	109.5	111.5
40%	1.94E+09	154000	0.003	82.47	83.59	84.88	0.0042	108.6	110.4	112.3
45%	2.45E+09	159500	0.00295	83.16	84.3	85.64	0.00413	109.3	111.1	113.2
50%	3.03E+09	165000	0.00291	83.86	85.04	86.41	0.00406	110	111.9	114

Table L.14. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 2634 kN and 2943 kN.

			P=2634 kN (280, 290, 300 kN)				P=2943 kN (320, 330, 340 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	EIcurrent $(KN.m^2)$	A/B/C	A	B	C	A/B/C	A	B	C
50%	3.03E+09	55000	0.00912	105.3	108.1	112.7	0.0116	129.2	131.3	133
45%	2.45E+09	60500	0.00857	106.9	108.2	111.7	0.0108	130	132.2	134.1
40%	1.94E+09	66000	0.00811	108.4	109.9	111.2	0.0102	131	133.2	135.2
35%	1.48E+09	71500	0.00772	109.8	111.4	112.8	0.00965	132.2	134.5	136.5
30%	1.09E+09	77000	0.00738	111.2	112.8	114.4	0.00918	133.2	135.6	137.7
25%	7.56E+08	82500	0.0071	112.7	114.4	116	0.00878	134.2	136.6	138.9
20%	4.84E+08	88000	0.00683	113.9	115.7	117.4	0.00843	135.2	137.7	140
15%	2.72E+08	93500	0.0066	115.1	116.9	118.8	0.00812	136.2	138.7	141.1
10%	1.21E+08	99000	0.00638	116.2	118.1	120	0.00785	137.3	139.9	142.4
5%	3.03E+07	104500	0.00621	117.5	119.4	121.4	0.0076	138.2	140.8	143.4
0%	0.00E+00	110000	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
5%	3.03E+07	115500	0.00586	119.4	121.5	123.6	0.00714	139.9	142.5	145.2
10%	1.21E+08	121000	0.00572	120.3	122.4	124.6	0.00697	140.8	143.7	146.3
15%	2.72E+08	126500	0.00558	121.3	123.4	125.6	0.00679	141.6	144.6	147.3
20%	4.84E+08	132000	0.00545	122	124.2	126.4	0.00663	142.3	145.4	148.2
25%	7.56E+08	137500	0.00533	123	125.1	127.4	0.00648	143	146.2	149.2
30%	1.09E+09	143000	0.00522	123.8	126	128.3	0.00633	143.5	146.8	149.9
35%	1.48E+09	148500	0.00512	124.6	126.9	129.3	0.00621	144.2	147.6	150.8
40%	1.94E+09	154000	0.00503	125.4	127.8	130.2	0.00608	144.8	148.2	151.6
45%	2.45E+09	159500	0.00494	126.1	128.6	131	0.00597	145.4	148.9	152.3
50%	3.03E+09	165000	0.00485	126.7	129.4	131.9	0.00586	146	149.6	153.1

Table L.15(a) Value of $COV(Y_{Top})$ for fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1907 kN and 2356 kN.

		P=1907 kN		P=2356 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	3.03E+07	8.10E-09	2.542%	1.56E-08	2.500%
10%	1.21E+08	3.24E-08	5.085%	6.50E-08	5.100%
15%	2.72E+08	7.29E-08	7.627%	1.56E-07	7.900%
20%	4.84E+08	1.30E-07	10.169%	2.81E-07	10.600%
25%	7.56E+08	2.16E-07	13.136%	4.69E-07	13.700%
30%	1.09E+09	3.25E-07	16.102%	7.06E-07	16.800%
35%	1.48E+09	4.69E-07	19.350%	1.03E-06	20.300%
40%	1.94E+09	6.64E-07	23.023%	1.45E-06	24.100%
45%	2.45E+09	9.22E-07	27.119%	1.99E-06	28.200%
50%	3.03E+09	1.24E-06	31.497%	2.74E-06	33.100%

Table L.15(b) Value of $COV(Y_{Top})$ for fixed head long pile (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 2634 kN and 2943 kN.

		P=2634 kN		P=2943 kN	
COV(EI) (%)	Var (EI) $(kN.m^2)^2$	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)	$VAR(Y_{Top})$ (m^2)	$COV(Y_{Top})$ (%)
5%	3.03E+07	3.06E-08	2.902%	5.29E-08	3.121%
10%	1.21E+08	1.09E-07	5.473%	1.94E-07	5.970%
15%	2.72E+08	2.60E-07	8.458%	4.42E-07	9.023%
20%	4.84E+08	4.76E-07	11.443%	8.10E-07	12.212%
25%	7.56E+08	7.83E-07	14.677%	1.32E-06	15.604%
30%	1.09E+09	1.17E-06	17.910%	2.03E-06	19.335%
35%	1.48E+09	1.69E-06	21.559%	2.96E-06	23.338%
40%	1.94E+09	2.37E-06	25.539%	4.24E-06	27.951%
45%	2.45E+09	3.29E-06	30.100%	5.83E-06	32.768%
50%	3.03E+09	4.56E-06	35.406%	8.24E-06	38.942%

Table L.16(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 1907 kN.

		P=1907 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	1.050625	1.155625	0.0025	1.35%	1.41%	0.06%
10%	1.21E+08	4.100625	2.25	0.2116	2.67%	1.96%	0.59%
15%	2.72E+08	8.41	3.2761	0.680625	3.83%	2.37%	1.06%
20%	4.84E+08	10.0489	4.473225	1.3924	4.19%	2.77%	1.51%
25%	7.56E+08	11.799225	5.880625	0.94249	4.54%	3.17%	1.24%
30%	1.09E+09	13.4689	7.317025	3.478225	4.85%	3.54%	2.39%
35%	1.48E+09	15.171025	8.7616	4.7089	5.14%	3.87%	2.78%
40%	1.94E+09	16.7281	10.3041	6.1009	5.40%	4.20%	3.16%
45%	2.45E+09	18.275625	11.7649	7.535025	5.64%	4.48%	3.51%
50%	3.03E+09	19.8916	13.432225	9.1809	5.89%	4.79%	3.88%

Table L.16(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 2356 kN.

		P=2356 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	1.21	1.44	1.5625	1.08%	1.17%	1.20%
10%	1.21E+08	4.515625	5.0625	5.76	2.10%	2.19%	2.30%
15%	2.72E+08	10.4329	11.4244	12.6025	3.19%	3.28%	3.40%
20%	4.84E+08	18.619225	20.7025	23.3289	4.26%	4.42%	4.62%
25%	7.56E+08	29.757025	32.8329	36.542025	5.38%	5.57%	5.78%
30%	1.09E+09	42.968025	48.094225	38.254225	6.46%	6.74%	5.92%
35%	1.48E+09	60.5284	52.200625	39.879225	7.67%	7.02%	6.04%
40%	1.94E+09	70.7281	53.509225	40.768225	8.29%	7.11%	6.11%
45%	2.45E+09	70.2244	52.780225	41.6025	8.26%	7.06%	6.17%
50%	3.03E+09	69.5556	52.5625	41.6025	8.22%	7.05%	6.17%

Table L.16(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 2634 kN.

		P=2634 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.9025	1.1025	1.21	0.80%	0.87%	0.90%
10%	1.21E+08	4.2025	4.6225	5.29	1.73%	1.79%	1.88%
15%	2.72E+08	9.61	10.5625	11.56	2.62%	2.70%	2.78%
20%	4.84E+08	16.4025	18.0625	20.25	3.42%	3.53%	3.68%
25%	7.56E+08	26.5225	28.6225	32.49	4.35%	4.44%	4.66%
30%	1.09E+09	39.69	43.56	48.3025	5.32%	5.48%	5.68%
35%	1.48E+09	54.76	60.0625	68.0625	6.25%	6.44%	6.74%
40%	1.94E+09	72.25	80.1025	90.25	7.18%	7.43%	7.76%
45%	2.45E+09	92.16	104.04	93.1225	8.11%	8.47%	7.88%
50%	3.03E+09	114.49	113.4225	92.16	9.04%	8.85%	7.84%

Table L.16(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'EI' and lateral load 2943 kN.

		P=2943 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(EI) (%)	Var (EI) (kN.m^2)^2	A	B	C	A	B	C
5%	3.03E+07	0.7225	0.7225	0.81	0.61%	0.60%	0.62%
10%	1.21E+08	3.0625	3.61	3.8025	1.26%	1.34%	1.35%
15%	2.72E+08	7.29	8.7025	9.61	1.94%	2.08%	2.15%
20%	4.84E+08	12.6025	14.8225	16.81	2.55%	2.72%	2.84%
25%	7.56E+08	19.36	23.04	26.5225	3.16%	3.39%	3.57%
30%	1.09E+09	26.5225	31.36	37.21	3.70%	3.95%	4.22%
35%	1.48E+09	36	42.9025	51.1225	4.31%	4.62%	4.95%
40%	1.94E+09	47.61	56.25	67.24	4.96%	5.29%	5.68%
45%	2.45E+09	59.29	69.7225	82.81	5.53%	5.89%	6.30%
50%	3.03E+09	70.56	83.7225	101.0025	6.03%	6.45%	6.96%

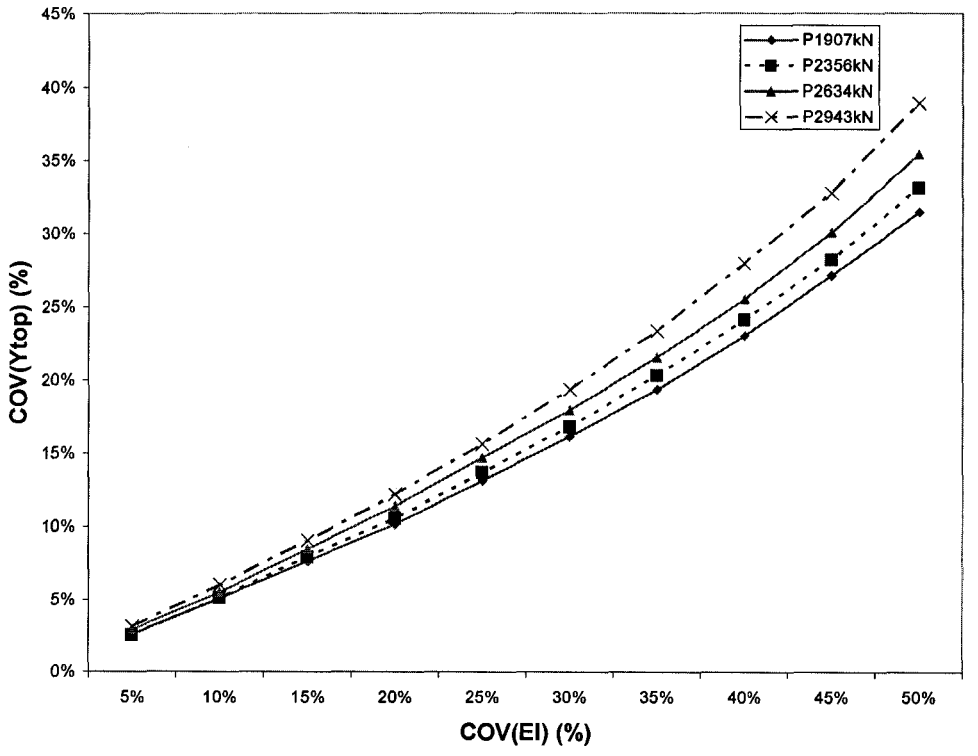

Fig. L.7 COV(Y_{Top}) for varying COV(EI) in fixed head long (10T) pile group with spacing (5D).

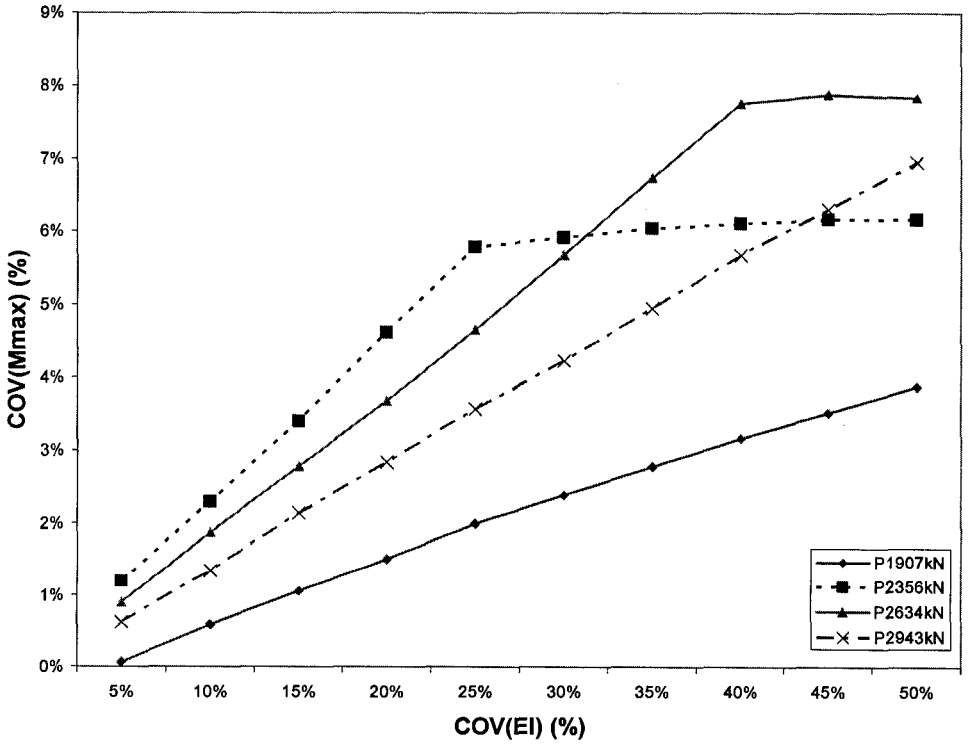

Fig. L.8(a) COV(M_{Max}) for varying COV(EI) for pile C in fixed head long pile group with spacing (5D).

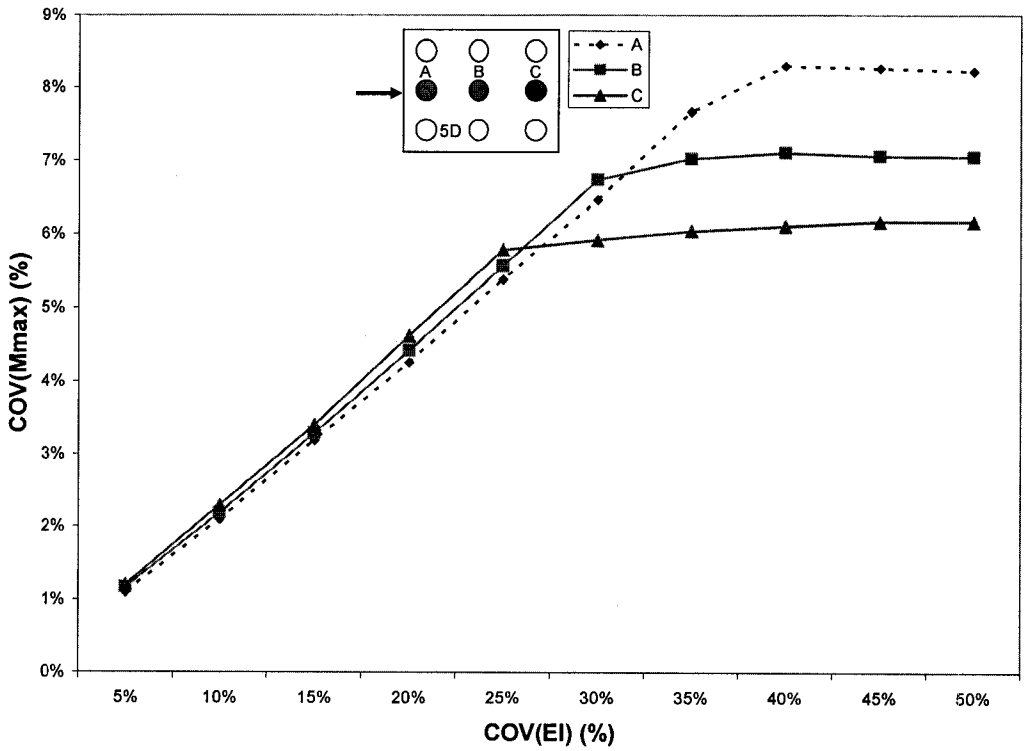

Fig. L.8(b) COV(M_{Max}) for varying COV(EI) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (5D) at the optimum lateral load 2356 kN.

L.1.5 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (5D) and with 'k' as varying random design variable

Table L.17. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1907 kN and 2356 kN.

			P=1907 kN (200, 210, 220 kN)				P=2356 kN (250, 260, 270 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00356	75.04	75.11	77.34	0.00498	101.2	102.7	104.3
45%	3.75E+09	74800	0.00355	75.68	76.42	77.61	0.00498	101.3	102.8	104.4
40%	2.96E+09	81600	0.00354	75.71	76.45	77.77	0.00498	101.3	102.8	104.4
35%	2.27E+09	88400	0.00354	75.75	76.49	77.84	0.00498	101.3	102.8	104.4
30%	1.66E+09	95200	0.00354	75.76	76.52	77.91	0.00498	101.3	102.8	104.4
25%	1.16E+09	102000	0.00354	75.75	76.51	77.96	0.005	101.4	102.9	104.5
20%	7.40E+08	108800	0.00354	75.75	76.5	78	0.005	101.4	102.9	104.5
15%	4.16E+08	115600	0.00354	75.75	76.5	78.03	0.005	101.4	102.9	104.5
10%	1.85E+08	122400	0.00354	75.74	76.49	78.06	0.005	101.4	102.9	104.5
5%	4.62E+07	129200	0.00354	75.74	76.49	78.09	0.005	101.4	102.9	104.5
0%	0.00E+00	136000	0.00354	75.74	76.48	78.12	0.005	101.4	102.9	104.5
5%	4.62E+07	142800	0.00354	75.73	76.48	78.13	0.005	101.4	102.9	104.4
10%	1.85E+08	149600	0.00354	75.73	76.47	78.14	0.005	101.4	102.9	104.4
15%	4.16E+08	156400	0.00354	75.72	76.47	78.14	0.005	101.4	102.9	104.4
20%	7.40E+08	163200	0.00353	75.65	76.41	78.2	0.005	101.4	102.9	104.4
25%	1.16E+09	170000	0.00353	75.64	76.41	78.2	0.005	101.4	102.8	104.4
30%	1.66E+09	176800	0.00353	75.64	76.42	78.21	0.005	101.4	102.8	104.4
35%	2.27E+09	183600	0.00353	75.63	76.42	78.21	0.005	101.4	102.8	104.4
40%	2.96E+09	190400	0.00353	75.63	76.42	78.21	0.005	101.4	102.8	104.4
45%	3.75E+09	197200	0.00353	75.63	76.42	78.21	0.00498	101.2	102.7	104.3
50%	4.62E+09	204000	0.00353	75.63	76.42	78.21	0.00498	101.2	102.7	104.2

Table L.18. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 2634 kN and 2943 kN.

			P=2634 kN (280, 290, 300 kN)				P=2943 kN (320, 330, 340 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(k) (%)	Var (k) $(kN/m^3)^2$	kcurrent (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	4.62E+09	68000	0.00603	118.3	120.4	122.5	0.00738	138.8	141.6	144.4
45%	3.75E+09	74800	0.00603	118.3	120.4	122.5	0.00738	138.8	141.8	144.4
40%	2.96E+09	81600	0.00603	118.3	120.4	122.5	0.00737	138.9	141.8	144.4
35%	2.27E+09	88400	0.00603	118.4	120.4	122.5	0.00737	138.9	141.8	144.4
30%	1.66E+09	95200	0.00603	118.4	120.4	122.5	0.00737	138.9	141.8	144.4
25%	1.16E+09	102000	0.00603	118.4	120.4	122.5	0.00737	139	141.8	144.4
20%	7.40E+08	108800	0.00603	118.4	120.4	122.5	0.00737	139	141.8	144.4
15%	4.16E+08	115600	0.00603	118.4	120.4	122.5	0.00737	139.1	141.8	144.4
10%	1.85E+08	122400	0.00603	118.4	120.4	122.5	0.00737	139.1	141.8	144.4
5%	4.62E+07	129200	0.00603	118.4	120.4	122.5	0.00737	139.2	141.8	144.4
0%	0.00E+00	136000	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
5%	4.62E+07	142800	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
10%	1.85E+08	149600	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
15%	4.16E+08	156400	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
20%	7.40E+08	163200	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
25%	1.16E+09	170000	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
30%	1.66E+09	176800	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
35%	2.27E+09	183600	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
40%	2.96E+09	190400	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
45%	3.75E+09	197200	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2
50%	4.62E+09	204000	0.00603	118.4	120.4	122.4	0.00735	139.2	141.8	144.2

Table L.19(a) Value of COV(Y_{Top}) for fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1907 kN and 2356 kN.

		P=1907 kN		P=2356 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	0.00E+00	0.000%
15%	4.16E+08	0.00E+00	0.000%	0.00E+00	0.000%
20%	7.40E+08	2.50E-11	0.141%	0.00E+00	0.000%
25%	1.16E+09	2.50E-11	0.141%	0.00E+00	0.000%
30%	1.66E+09	2.50E-11	0.141%	1.00E-10	0.200%
35%	2.27E+09	2.50E-11	0.141%	1.00E-10	0.200%
40%	2.96E+09	2.50E-11	0.141%	1.00E-10	0.200%
45%	3.75E+09	1.00E-10	0.282%	0.00E+00	0.000%
50%	4.62E+09	2.25E-10	0.424%	0.00E+00	0.000%

Table L.19(b) Value of COV(Y_{Top}) for fixed head long pile (10T) pile group with spacing (5D) and with varying 'k' and lateral load 2634 kN and 2943 kN

		P=2634 kN		P=2943 kN	
COV(k) (%)	Var (k) $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	4.62E+07	0.00E+00	0.000%	0.00E+00	0.000%
10%	1.85E+08	0.00E+00	0.000%	1.00E-10	0.136%
15%	4.16E+08	0.00E+00	0.000%	1.00E-10	0.136%
20%	7.40E+08	0.00E+00	0.000%	1.00E-10	0.136%
25%	1.16E+09	0.00E+00	0.000%	1.00E-10	0.136%
30%	1.66E+09	0.00E+00	0.000%	1.00E-10	0.136%
35%	2.27E+09	0.00E+00	0.000%	1.00E-10	0.136%
40%	2.96E+09	0.00E+00	0.000%	1.00E-10	0.136%
45%	3.75E+09	0.00E+00	0.000%	2.25E-10	0.204%
50%	4.62E+09	0.00E+00	0.000%	2.25E-10	0.204%

Table L.20(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 1907 kN.

		P=1907 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	2.50E-05	2.50E-05	4.00E-04	0.01%	0.01%	0.03%
10%	1.85E+08	2.50E-05	1.00E-04	1.60E-03	0.01%	0.01%	0.05%
15%	4.16E+08	2.25E-04	2.25E-04	3.02E-03	0.02%	0.02%	0.07%
20%	7.40E+08	2.50E-03	2.03E-03	1.00E-02	0.07%	0.06%	0.13%
25%	1.16E+09	3.02E-03	2.50E-03	5.76E-03	0.07%	0.07%	0.10%
30%	1.66E+09	3.60E-03	2.50E-03	2.25E-02	0.08%	0.07%	0.19%
35%	2.27E+09	3.60E-03	1.22E-03	3.42E-02	0.08%	0.05%	0.24%
40%	2.96E+09	1.60E-03	2.25E-04	4.84E-02	0.05%	0.02%	0.28%
45%	3.75E+09	6.25E-04	0.00E+00	9.00E-02	0.03%	0.00%	0.38%
50%	4.62E+09	8.70E-02	4.29E-01	1.89E-01	0.39%	0.86%	0.56%

Table L.20(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 2356 kN.

		P=2356 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.05%
10%	1.85E+08	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.05%
15%	4.16E+08	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.05%
20%	7.40E+08	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.05%
25%	1.16E+09	0.00E+00	2.50E-03	2.50E-03	0.00%	0.05%	0.05%
30%	1.66E+09	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
35%	2.27E+09	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
40%	2.96E+09	2.50E-03	0.00E+00	0.00E+00	0.05%	0.00%	0.00%
45%	3.75E+09	2.50E-03	2.50E-03	2.50E-03	0.05%	0.05%	0.05%
50%	4.62E+09	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.05%

Table L.20(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 2634 kN.

		P=2634 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
10%	1.85E+08	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
15%	4.16E+08	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
20%	7.40E+08	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
25%	1.16E+09	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
30%	1.66E+09	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
35%	2.27E+09	0.00E+00	0.00E+00	2.50E-03	0.00%	0.00%	0.04%
40%	2.96E+09	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%
45%	3.75E+09	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%
50%	4.62E+09	2.50E-03	0.00E+00	2.50E-03	0.04%	0.00%	0.04%

Table L.20(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'k' and lateral load 2943 kN.

		P=2943 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(k) (%)	Var (k) (kN/m^3)^2	A	B	C	A	B	C
5%	4.62E+07	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%	0.00%
10%	1.85E+08	2.50E-03	0.00E+00	1.00E-02	0.04%	0.00%	0.07%
15%	4.16E+08	2.50E-03	0.00E+00	1.00E-02	0.04%	0.00%	0.07%
20%	7.40E+08	1.00E-02	0.00E+00	1.00E-02	0.07%	0.00%	0.07%
25%	1.16E+09	1.00E-02	0.00E+00	1.00E-02	0.07%	0.00%	0.07%
30%	1.66E+09	2.25E-02	0.00E+00	1.00E-02	0.11%	0.00%	0.07%
35%	2.27E+09	2.25E-02	0.00E+00	1.00E-02	0.11%	0.00%	0.07%
40%	2.96E+09	2.25E-02	0.00E+00	1.00E-02	0.11%	0.00%	0.07%
45%	3.75E+09	4.00E-02	0.00E+00	1.00E-02	0.14%	0.00%	0.07%
50%	4.62E+09	4.00E-02	1.00E-02	1.00E-02	0.14%	0.07%	0.07%

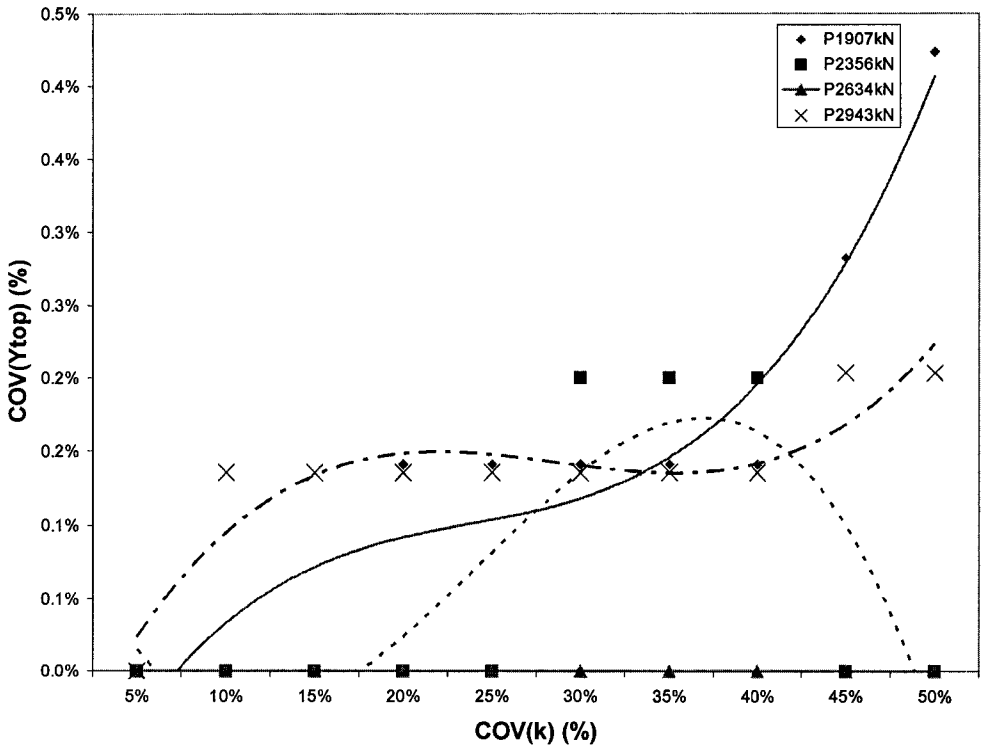

Fig. L.9 COV(Y_{Top}) for varying COV(k) in fixed head long (10T) pile group with spacing (5D).

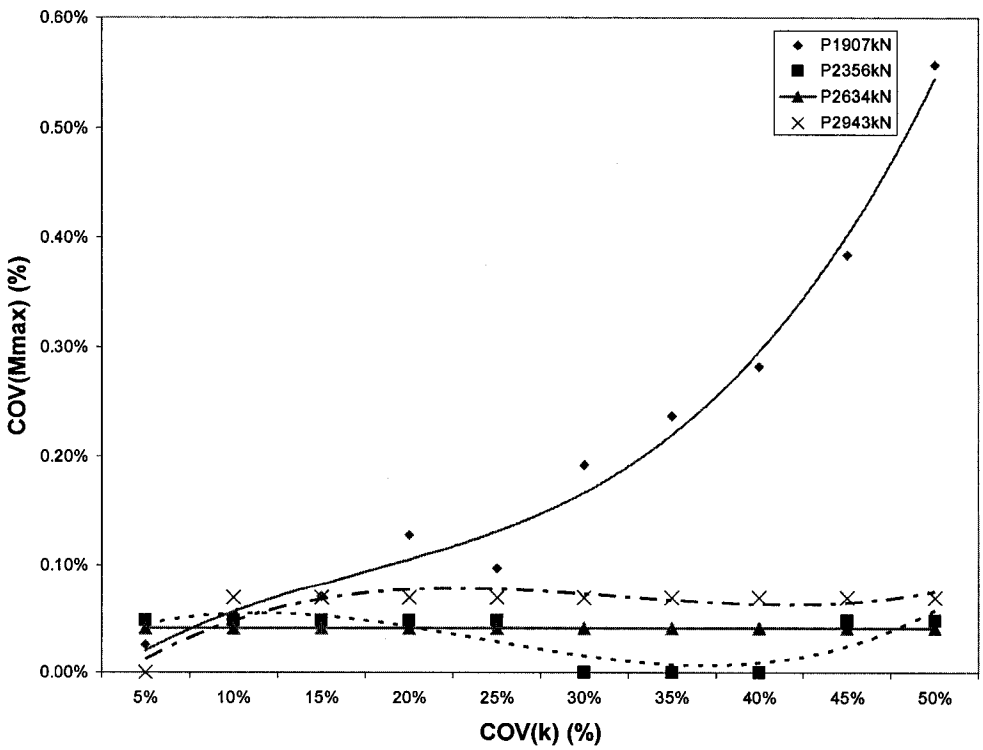

Fig. L.10(a) COV(M_{Max}) for varying COV(k) for pile C in fixed head long pile group with spacing (5D).

Note: Value of COV(M_{MAX}) is zero for pile rows A, B, C with varying COV(k) at optimum load 2356 kN in free head long (10T) pile group with spacing (5D).

L.1.6 Probabilistic modeling of laterally loaded fixed head long (10T) pile group with spacing (5D) and with 'γ'' as varying random design variable

Table L.21. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1907 kN and 2356 kN.

			P=1907 kN (200, 210, 220 kN)				P=2356 kN (250, 260, 270 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00355	75.95	76.7	78.21	0.00502	101.7	103.2	104.7
45%	7.049025	3.245	0.00355	75.93	76.68	78.2	0.00501	101.6	103.1	104.7
40%	5.5696	3.54	0.00355	75.91	76.66	78.19	0.00501	101.6	103.1	104.7
35%	4.264225	3.835	0.00355	75.89	76.64	78.18	0.00501	101.6	103.1	104.6
30%	3.1329	4.13	0.00355	75.86	76.61	78.17	0.00501	101.6	103	104.6
25%	2.175625	4.425	0.00355	75.84	76.59	78.16	0.00501	101.5	103	104.6
20%	1.3924	4.72	0.00355	75.82	76.57	78.15	0.00501	101.5	103	104.6
15%	0.783225	5.015	0.00355	75.8	76.55	78.14	0.00501	101.5	103	104.5
10%	0.3481	5.31	0.00354	75.78	76.53	78.13	0.005	101.5	102.9	104.5
5%	0.087025	5.605	0.00354	75.76	76.5	78.13	0.005	101.4	102.9	104.5
0%	0	5.9	0.00354	75.74	76.48	78.12	0.005	101.4	102.9	104.5
5%	0.087025	6.195	0.00354	75.71	76.46	78.11	0.005	101.4	102.9	104.4
10%	0.3481	6.49	0.00354	75.69	76.44	78.1	0.005	101.4	102.8	104.4
15%	0.783225	6.785	0.00354	75.67	76.41	78.09	0.005	101.3	102.8	104.4
20%	1.3924	7.08	0.00354	75.65	76.39	78.08	0.00499	101.3	102.8	104.3
25%	2.175625	7.375	0.00354	75.63	76.37	78.07	0.00499	101.3	102.8	104.3
30%	3.1329	7.67	0.00354	75.61	76.35	78.06	0.00499	101.2	102.7	104.3
35%	4.264225	7.965	0.00354	75.59	76.33	78.05	0.00499	101.2	102.7	104.3
40%	5.5696	8.26	0.00353	75.56	76.3	78.05	0.00499	101.2	102.7	104.2
45%	7.049025	8.555	0.00353	75.54	76.28	78.04	0.00499	101.2	102.6	104.2
50%	8.7025	8.85	0.00353	75.52	76.26	78.03	0.00499	101.1	102.6	104.2

Table L.22. Values of Y_{Top} and M_{Max} for rows A, B, C of fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 2634 kN and 2943 kN.

			P=2634 kN (280, 290, 300 kN)				P=2943 kN (320, 330, 340 kN)			
			Ytop (m)	Mmax (kN-m)			Ytop (m)	Mmax (kN-m)		
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	γ' current (kN/m^3)	A/B/C	A	B	C	A/B/C	A	B	C
50%	8.7025	2.95	0.00605	118.7	120.8	122.8	0.00739	139.5	142.1	144.7
45%	7.049025	3.245	0.00605	118.7	120.7	122.8	0.00739	139.5	142.1	144.7
40%	5.5696	3.54	0.00605	118.7	120.7	122.8	0.00739	139.4	142	144.7
35%	4.264225	3.835	0.00604	118.6	120.7	122.7	0.00738	139.4	142	144.6
30%	3.1329	4.13	0.00604	118.6	120.6	122.7	0.00738	139.4	142	144.6
25%	2.175625	4.425	0.00604	118.6	120.6	122.7	0.00738	139.3	141.9	144.6
20%	1.3924	4.72	0.00604	118.6	120.6	122.6	0.00738	139.3	141.9	144.5
15%	0.783225	5.015	0.00604	118.5	120.5	122.6	0.00737	139.3	141.9	144.5
10%	0.3481	5.31	0.00604	118.5	120.5	122.6	0.00737	139.2	141.8	144.4
5%	0.087025	5.605	0.00603	118.4	120.5	122.5	0.00737	139.2	141.8	144.4
0%	0	5.9	0.00603	118.4	120.4	122.4	0.00737	139.2	141.8	144.4
5%	0.087025	6.195	0.00603	118.4	120.4	122.4	0.00736	139.1	141.7	144.3
10%	0.3481	6.49	0.00602	118.3	120.3	122.4	0.00736	139.1	141.7	144.3
15%	0.783225	6.785	0.00602	118.3	120.3	122.4	0.00736	139.1	141.7	144.3
20%	1.3924	7.08	0.00602	118.3	120.3	122.3	0.00736	139	141.6	144.2
25%	2.175625	7.375	0.00602	118.2	120.2	122.3	0.00736	139	141.6	144.2
30%	3.1329	7.67	0.00602	118.2	120.2	122.3	0.00735	139	141.5	144.2
35%	4.264225	7.965	0.00601	118.2	120.2	122.2	0.00735	138.9	141.5	144.1
40%	5.5696	8.26	0.00601	118.2	120.2	122.2	0.00735	138.9	141.5	144.1
45%	7.049025	8.555	0.00601	118.1	120.1	122.2	0.00735	138.9	141.4	144
50%	8.7025	8.85	0.00601	118.1	120.1	122.1	0.00734	138.8	141.4	144

Table L.23(a) Value of $COV(Y_{Top})$ for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1907 kN and 2356 kN.

		P=1907 kN		P=2356 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	0.00E+00	0.000%
10%	0.3481	0.00E+00	0.000%	0.00E+00	0.000%
15%	0.783225	2.50E-11	0.141%	2.50E-11	0.100%
20%	1.3924	2.50E-11	0.141%	1.00E-10	0.200%
25%	2.175625	2.50E-11	0.141%	1.00E-10	0.200%
30%	3.1329	2.50E-11	0.141%	1.00E-10	0.200%
35%	4.264225	2.50E-11	0.141%	1.00E-10	0.200%
40%	5.5696	1.00E-10	0.282%	1.00E-10	0.200%
45%	7.049025	1.00E-10	0.282%	1.00E-10	0.200%
50%	8.7025	1.00E-10	0.282%	2.25E-10	0.300%

Table L.23(b) Value of $COV(Y_{Top})$ for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 2634 kN and 2943 kN.

		P=2634 kN		P=2943 kN	
COV(γ') (%)	Var(γ') $(kN/m^3)^2$	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)	VAR(Y_{Top}) (m^2)	COV(Y_{Top}) (%)
5%	0.087025	0.00E+00	0.000%	2.50E-11	0.068%
10%	0.3481	1.00E-10	0.166%	2.50E-11	0.068%
15%	0.783225	1.00E-10	0.166%	2.50E-11	0.068%
20%	1.3924	1.00E-10	0.166%	1.00E-10	0.136%
25%	2.175625	1.00E-10	0.166%	1.00E-10	0.136%
30%	3.1329	1.00E-10	0.166%	2.25E-10	0.204%
35%	4.264225	2.25E-10	0.249%	2.25E-10	0.204%
40%	5.5696	4.00E-10	0.332%	4.00E-10	0.271%
45%	7.049025	4.00E-10	0.332%	4.00E-10	0.271%
50%	8.7025	4.00E-10	0.332%	6.25E-10	0.339%

Table L.24(a) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 1907 kN.

		P=1907 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.000625	0.0004	1E-04	0.03%	0.03%	0.01%
10%	0.3481	0.002025	0.002025	0.000225	0.06%	0.06%	0.02%
15%	0.783225	0.004225	0.0049	0.000625	0.09%	0.09%	0.03%
20%	1.3924	0.007225	0.0081	0.001225	0.11%	0.12%	0.04%
25%	2.175625	0.011025	0.0121	0.00081	0.14%	0.14%	0.04%
30%	3.1329	0.015625	0.0169	0.003025	0.17%	0.17%	0.07%
35%	4.264225	0.0225	0.024025	0.004225	0.20%	0.20%	0.08%
40%	5.5696	0.030625	0.0324	0.0049	0.23%	0.24%	0.09%
45%	7.049025	0.038025	0.04	0.0064	0.26%	0.26%	0.10%
50%	8.7025	0.046225	0.0484	0.0081	0.28%	0.29%	0.12%

Table L.24(b) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 2356 kN.

		P=2356 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0	0	0.0025	0.00%	0.00%	0.05%
10%	0.3481	0.0025	0.0025	0.0025	0.05%	0.05%	0.05%
15%	0.783225	0.01	0.01	0.0025	0.10%	0.10%	0.05%
20%	1.3924	0.01	0.01	0.0225	0.10%	0.10%	0.14%
25%	2.175625	0.01	0.01	0.0225	0.10%	0.10%	0.14%
30%	3.1329	0.04	0.0225	0.0225	0.20%	0.15%	0.14%
35%	4.264225	0.04	0.04	0.0225	0.20%	0.19%	0.14%
40%	5.5696	0.04	0.04	0.0625	0.20%	0.19%	0.24%
45%	7.049025	0.04	0.0625	0.0625	0.20%	0.24%	0.24%
50%	8.7025	0.09	0.09	0.0625	0.30%	0.29%	0.24%

Table L.24(c) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 2634 kN.

		P=2634 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0	0.0025	0.0025	0.00%	0.04%	0.04%
10%	0.3481	0.01	0.01	0.01	0.08%	0.08%	0.08%
15%	0.783225	0.01	0.01	0.01	0.08%	0.08%	0.08%
20%	1.3924	0.0225	0.0225	0.0225	0.13%	0.12%	0.12%
25%	2.175625	0.04	0.04	0.04	0.17%	0.17%	0.16%
30%	3.1329	0.04	0.04	0.04	0.17%	0.17%	0.16%
35%	4.264225	0.04	0.0625	0.0625	0.17%	0.21%	0.20%
40%	5.5696	0.0625	0.0625	0.09	0.21%	0.21%	0.25%
45%	7.049025	0.09	0.09	0.09	0.25%	0.25%	0.25%
50%	8.7025	0.09	0.1225	0.1225	0.25%	0.29%	0.29%

Table L.24(d) Value of COV(M_{Max}) for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and lateral load 2943 kN.

		P=2943 kN					
		VAR(M_{Max}) (kN-m)^2			COV(M_{Max}) (%)		
COV(γ') (%)	Var(γ') (kN/m^3)^2	A	B	C	A	B	C
5%	0.087025	0.0025	0.0025	0.0025	0.04%	0.04%	0.03%
10%	0.3481	0.0025	0.0025	0.0025	0.04%	0.04%	0.03%
15%	0.783225	0.01	0.01	0.01	0.07%	0.07%	0.07%
20%	1.3924	0.0225	0.0225	0.0225	0.11%	0.11%	0.10%
25%	2.175625	0.0225	0.0225	0.04	0.11%	0.11%	0.14%
30%	3.1329	0.04	0.0625	0.04	0.14%	0.18%	0.14%
35%	4.264225	0.0625	0.0625	0.0625	0.18%	0.18%	0.17%
40%	5.5696	0.0625	0.0625	0.09	0.18%	0.18%	0.21%
45%	7.049025	0.09	0.1225	0.1225	0.22%	0.25%	0.24%
50%	8.7025	0.1225	0.1225	0.1225	0.25%	0.25%	0.24%

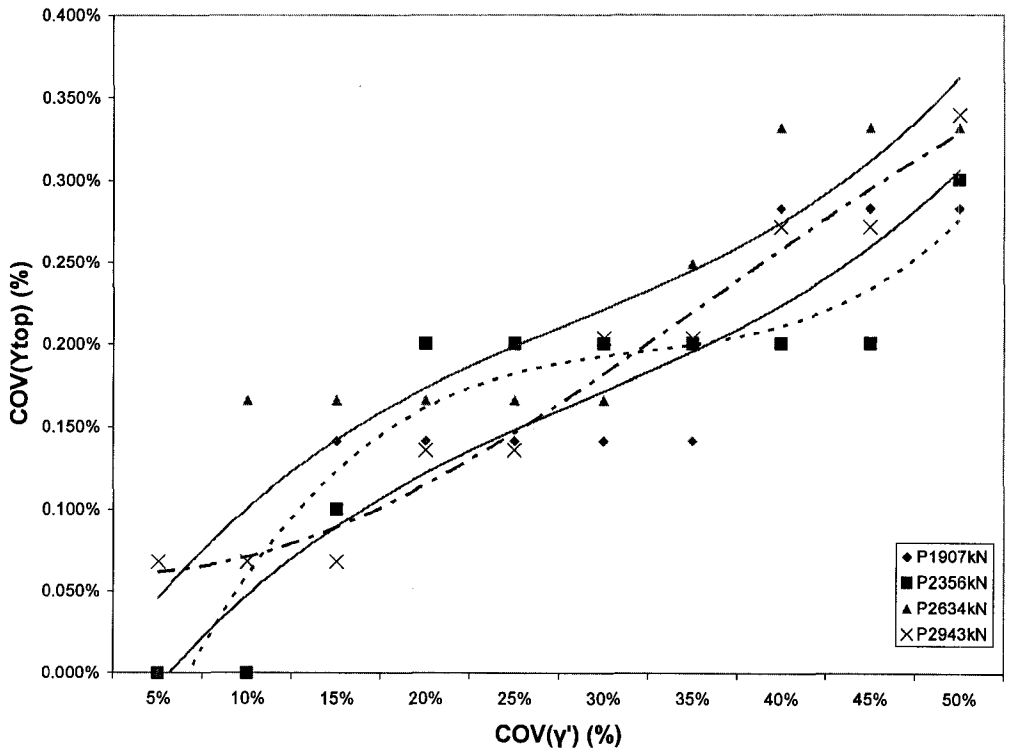

Fig. L.11 COV(Y_{Top}) for varying COV(γ') in fixed head long (10T) pile group with spacing (5D).

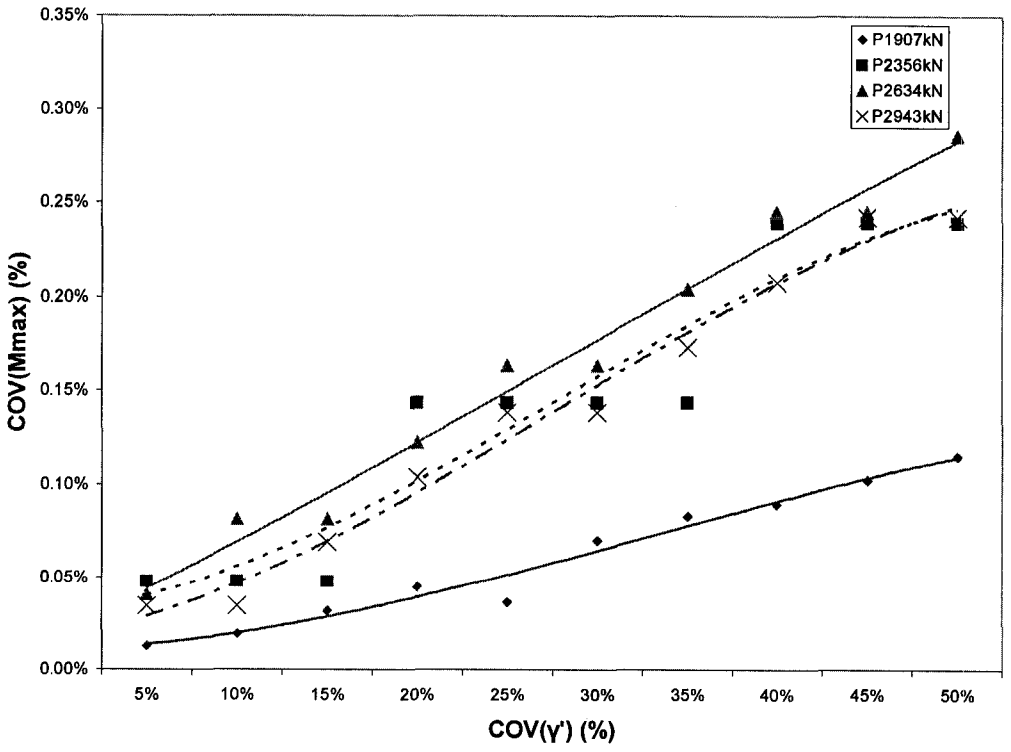

Fig. L.12(a) COV(M_{Max}) for varying COV(γ') for pile C in fixed head long pile group with spacing (5D).

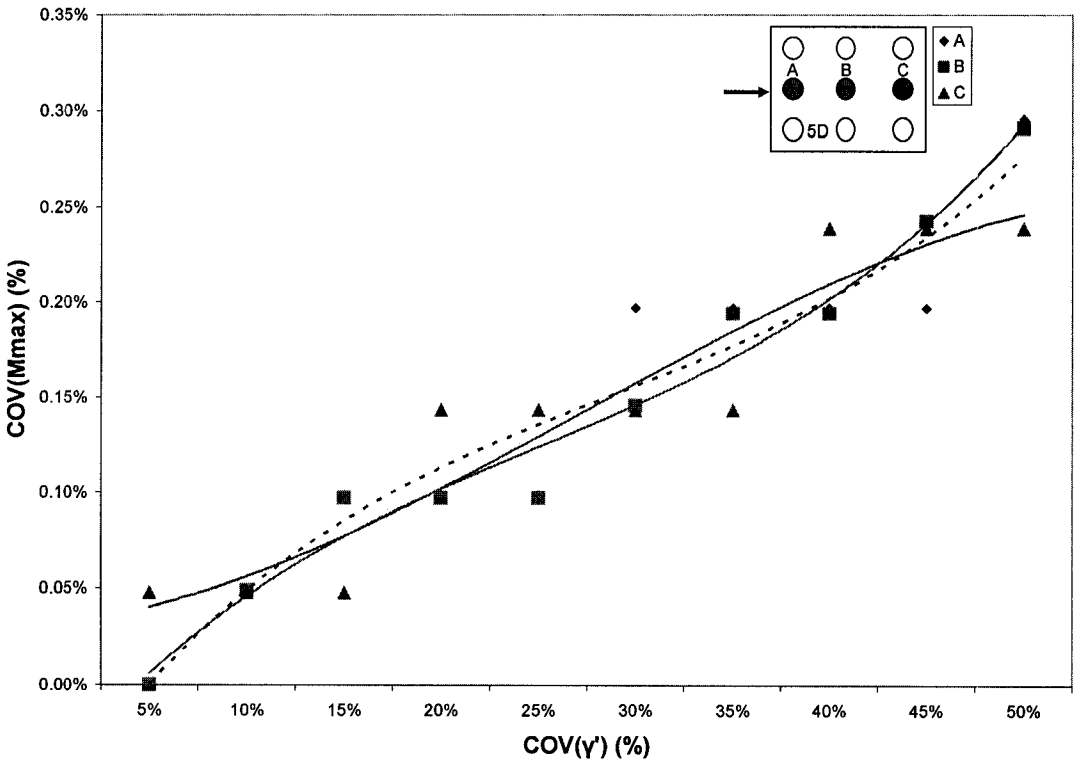

Fig. L.12 COV(M_{Max}) for varying COV(k) for pile rows A, B, and C in fixed head long (10T) pile group with spacing (5D) at the optimum lateral load 2356 kN.

K.2 Reliability analysis of fixed head long pile (10T) group with spacing (5D)

K.2.1 Reliability analysis for serviceability limit state (Y_{Top})

For lateral load 1907 kN

$g(Y_{top})^o = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.00946$ m and $VAR(Y_{top}^{Resist}) = 6.76E\text{-}06$ m^2

Table K.25 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 1907 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	3.02E-09	6.76E-06	3.64	3.06E-08	6.79E-06	3.63
10%	6.76E-06	1.21E-08	6.77E-06	3.64	1.26E-07	6.89E-06	3.61
15%	6.76E-06	2.89E-08	6.79E-06	3.63	2.92E-07	7.05E-06	3.56
20%	6.76E-06	5.52E-08	6.82E-06	3.62	5.33E-07	7.29E-06	3.50
25%	6.76E-06	8.12E-08	6.84E-06	3.62	8.56E-07	7.62E-06	3.43
30%	6.76E-06	1.19E-07	6.88E-06	3.61	1.31E-06	8.07E-06	3.33
35%	6.76E-06	1.76E-07	6.94E-06	3.59	1.95E-06	8.71E-06	3.21
40%	6.76E-06	3.08E-07	7.07E-06	3.56	2.89E-06	9.65E-06	3.05
45%	6.76E-06	Failed	Failed	Failed	4.28E-06	1.10E-05	2.85
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table L.26 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 1907 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	4.90E-09	6.76E-06	3.64	8.10E-09	6.77E-06	3.64
10%	6.76E-06	1.96E-08	6.78E-06	3.63	3.24E-08	6.79E-06	3.63
15%	6.76E-06	4.84E-08	6.81E-06	3.63	7.29E-08	6.83E-06	3.62
20%	6.76E-06	8.70E-08	6.85E-06	3.62	1.30E-07	6.89E-06	3.60
25%	6.76E-06	1.33E-07	6.89E-06	3.60	2.16E-07	6.98E-06	3.58
30%	6.76E-06	1.94E-07	6.95E-06	3.59	3.25E-07	7.08E-06	3.55
35%	6.76E-06	2.60E-07	7.02E-06	3.57	4.69E-07	7.23E-06	3.52
40%	6.76E-06	3.36E-07	7.10E-06	3.55	6.64E-07	7.42E-06	3.47
45%	6.76E-06	4.29E-07	7.19E-06	3.53	9.22E-07	7.68E-06	3.41
50%	6.76E-06	5.33E-07	7.29E-06	3.50	1.24E-06	8.00E-06	3.34

Table L.27 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 1907 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {$g(Y_{top})$} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
10%	6.76E-06	0.00E+00	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
15%	6.76E-06	2.50E-11	6.76E-06	3.64	0.00E+00	6.76E-06	3.64
20%	6.76E-06	2.50E-11	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
25%	6.76E-06	2.50E-11	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
30%	6.76E-06	2.50E-11	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
35%	6.76E-06	2.50E-11	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
40%	6.76E-06	1.00E-10	6.76E-06	3.64	2.50E-11	6.76E-06	3.64
45%	6.76E-06	1.00E-10	6.76E-06	3.64	1.00E-10	6.76E-06	3.64
50%	6.76E-06	1.00E-10	6.76E-06	3.64	2.25E-10	6.76E-06	3.64

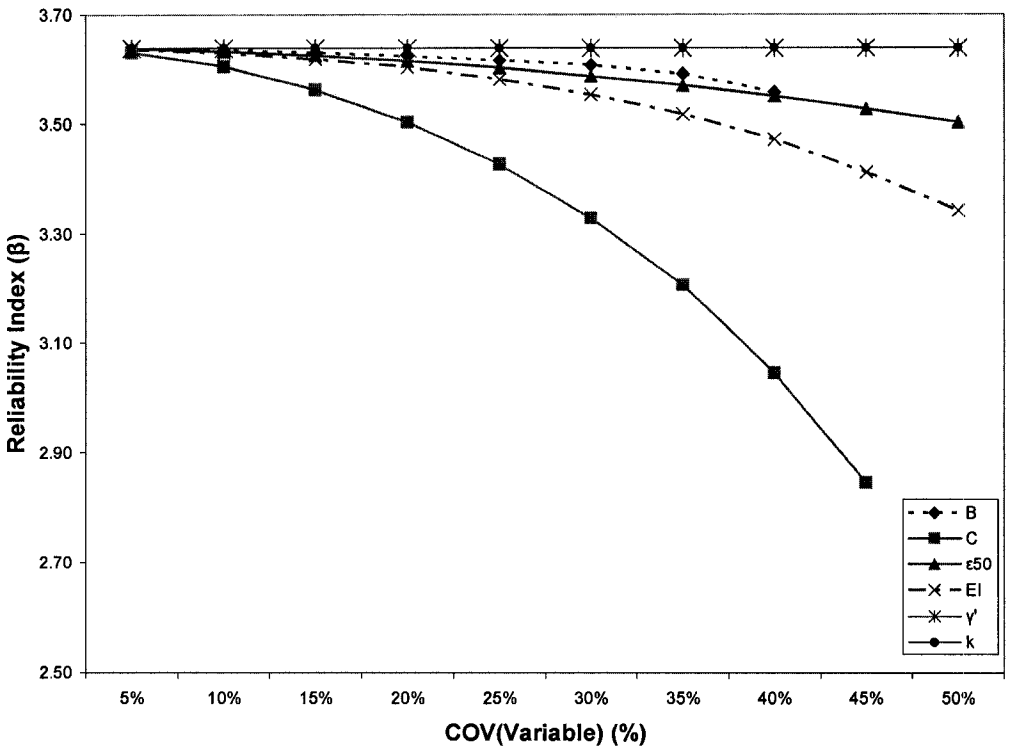

Fig. L.13 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (5D) at 1907 kN lateral load.

For lateral load 2356 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.008 \text{ m}$$

Table L.28 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 2356 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	7.23E-09	6.77E-06	3.08	6.25E-08	6.82E-06	3.06
10%	6.76E-06	3.42E-08	6.79E-06	3.07	2.70E-07	7.03E-06	3.02
15%	6.76E-06	8.70E-08	6.85E-06	3.06	6.24E-07	7.38E-06	2.94
20%	6.76E-06	1.64E-07	6.92E-06	3.04	1.20E-06	7.96E-06	2.84
25%	6.76E-06	2.92E-07	7.05E-06	3.01	2.03E-06	8.79E-06	2.70
30%	6.76E-06	4.42E-07	7.20E-06	2.98	3.26E-06	1.00E-05	2.53
35%	6.76E-06	7.23E-07	7.48E-06	2.92	4.93E-06	1.17E-05	2.34
40%	6.76E-06	1.29E-06	8.05E-06	2.82	7.40E-06	1.42E-05	2.13
45%	6.76E-06	Failed	Failed	Failed	1.14E-05	1.81E-05	1.88
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table L.29 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 2356 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.10E-08	6.77E-06	3.07	1.56E-08	6.78E-06	3.07
10%	6.76E-06	4.20E-08	6.80E-06	3.07	6.50E-08	6.83E-06	3.06
15%	6.76E-06	8.70E-08	6.85E-06	3.06	1.56E-07	6.92E-06	3.04
20%	6.76E-06	1.48E-07	6.91E-06	3.04	2.81E-07	7.04E-06	3.01
25%	6.76E-06	2.35E-07	7.00E-06	3.02	4.69E-07	7.23E-06	2.98
30%	6.76E-06	3.42E-07	7.10E-06	3.00	7.06E-07	7.47E-06	2.93
35%	6.76E-06	4.69E-07	7.23E-06	2.98	1.03E-06	7.79E-06	2.87
40%	6.76E-06	6.08E-07	7.37E-06	2.95	1.45E-06	8.21E-06	2.79
45%	6.76E-06	7.66E-07	7.53E-06	2.92	1.99E-06	8.75E-06	2.70
50%	6.76E-06	9.51E-07	7.71E-06	2.88	2.74E-06	9.50E-06	2.60

Table L.30 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 2356 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
10%	6.76E-06	0.00E+00	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
15%	6.76E-06	2.50E-11	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
20%	6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
25%	6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
30%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
35%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
40%	6.76E-06	1.00E-10	6.76E-06	3.08	1.00E-10	6.76E-06	3.08
45%	6.76E-06	1.00E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08
50%	6.76E-06	2.25E-10	6.76E-06	3.08	0.00E+00	6.76E-06	3.08

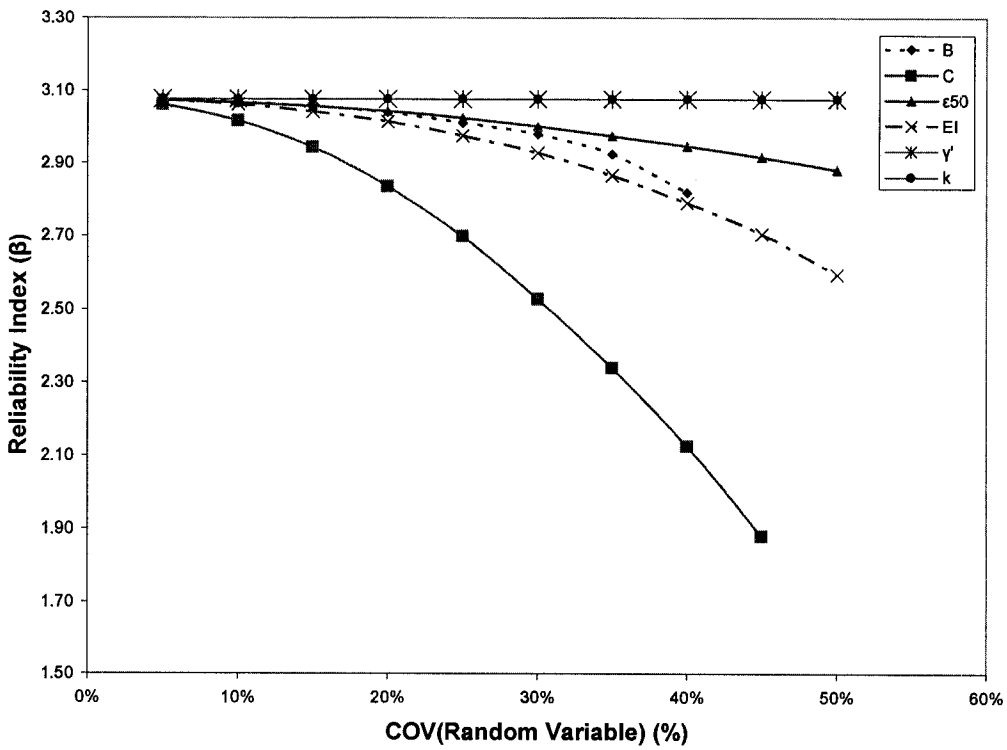

Fig. L.14 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (5D) at 2356 kN lateral load.

For lateral load 2634 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00697 \text{ m}$$

Table L.31 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 2634 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.69E-08	6.78E-06	2.68	1.06E-07	6.87E-06	2.66
10%	6.76E-06	7.56E-08	6.84E-06	2.67	4.42E-07	7.20E-06	2.60
15%	6.76E-06	1.89E-07	6.95E-06	2.64	1.06E-06	7.82E-06	2.49
20%	6.76E-06	3.66E-07	7.13E-06	2.61	1.99E-06	8.75E-06	2.36
25%	6.76E-06	6.32E-07	7.39E-06	2.56	3.39E-06	1.01E-05	2.19
30%	6.76E-06	1.01E-06	7.77E-06	2.50	5.41E-06	1.22E-05	2.00
35%	6.76E-06	1.68E-06	8.44E-06	2.40	8.38E-06	1.51E-05	1.79
40%	6.76E-06	3.33E-06	1.01E-05	2.19	1.31E-05	1.99E-05	1.56
45%	6.76E-06	Failed	Failed	Failed	2.16E-05	2.83E-05	1.31
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table L.32 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 2634 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.00E-08	6.77E-06	2.68	3.06E-08	6.79E-06	2.67
10%	6.76E-06	4.62E-08	6.81E-06	2.67	1.09E-07	6.87E-06	2.66
15%	6.76E-06	1.02E-07	6.86E-06	2.66	2.60E-07	7.02E-06	2.63
20%	6.76E-06	1.81E-07	6.94E-06	2.65	4.76E-07	7.24E-06	2.59
25%	6.76E-06	2.86E-07	7.05E-06	2.63	7.83E-07	7.54E-06	2.54
30%	6.76E-06	4.29E-07	7.19E-06	2.60	1.17E-06	7.93E-06	2.48
35%	6.76E-06	5.85E-07	7.35E-06	2.57	1.69E-06	8.45E-06	2.40
40%	6.76E-06	7.48E-07	7.51E-06	2.54	2.37E-06	9.13E-06	2.31
45%	6.76E-06	9.70E-07	7.73E-06	2.51	3.29E-06	1.01E-05	2.20
50%	6.76E-06	1.21E-06	7.97E-06	2.47	4.56E-06	1.13E-05	2.07

Table L.33 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 2634 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	0.00E+00	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
10%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
15%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
20%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
25%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
30%	6.76E-06	1.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
35%	6.76E-06	2.25E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
40%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
45%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68
50%	6.76E-06	4.00E-10	6.76E-06	2.68	0.00E+00	6.76E-06	2.68

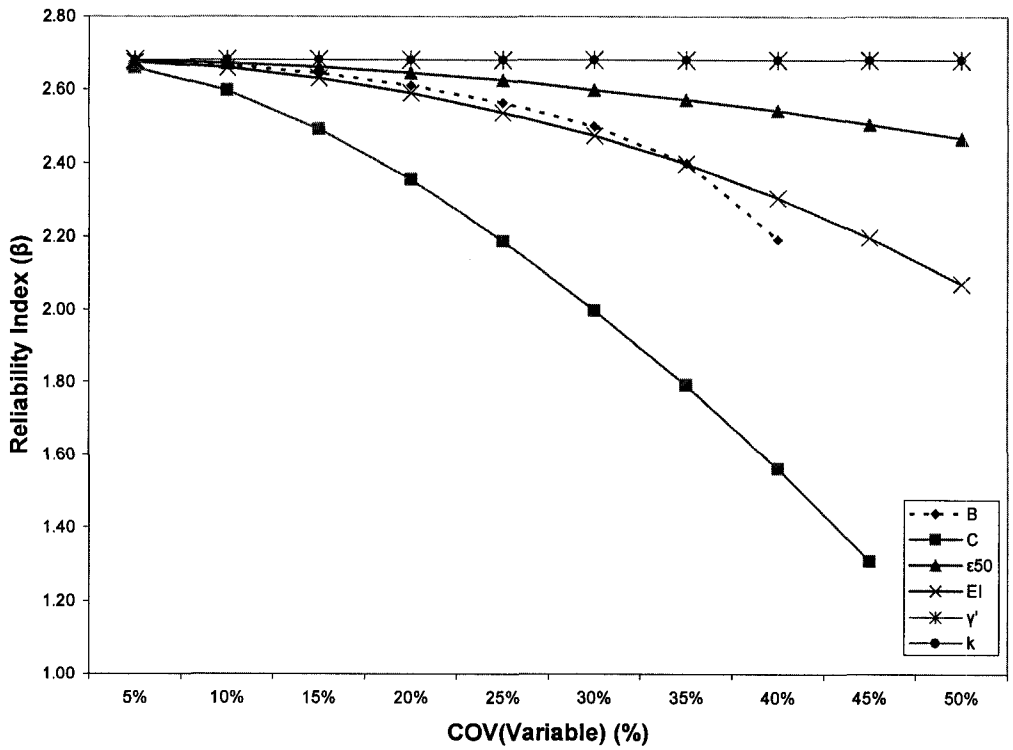

Fig. L.15 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (5D) at 2634 kN lateral load.

For lateral load 2943 kN

$$g(Y_{top})^{o} = Y_{top}^{Resisto} - Y_{top}^{Currento} = 0.00563 \text{ m}$$

Table L.34 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 2943 kN.

		B			C		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	3.80E-08	6.80E-06	2.16	1.85E-07	6.94E-06	2.14
10%	6.76E-06	1.72E-07	6.93E-06	2.14	7.74E-07	7.53E-06	2.05
15%	6.76E-06	4.23E-07	7.18E-06	2.10	1.85E-06	8.61E-06	1.92
20%	6.76E-06	8.37E-07	7.60E-06	2.04	3.52E-06	1.03E-05	1.76
25%	6.76E-06	1.50E-06	8.26E-06	1.96	6.15E-06	1.29E-05	1.57
30%	6.76E-06	2.61E-06	9.37E-06	1.84	9.86E-06	1.66E-05	1.38
35%	6.76E-06	5.93E-06	1.27E-05	1.58	1.64E-05	2.32E-05	1.17
40%	6.76E-06	Failed	Failed	Failed	2.81E-05	3.49E-05	0.95
45%	6.76E-06	Failed	Failed	Failed	5.46E-05	6.14E-05	0.72
50%	6.76E-06	Failed	Failed	Failed	Failed	Failed	Failed

Table L.35 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}' and 'EI' and applied lateral load 2943 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR $\{g(Y_{top})\}$ (m^2)	Reliability Index (β)
5%	6.76E-06	1.32E-08	6.77E-06	2.16	5.29E-08	6.81E-06	2.16
10%	6.76E-06	5.06E-08	6.81E-06	2.16	1.94E-07	6.95E-06	2.14
15%	6.76E-06	1.26E-07	6.89E-06	2.15	4.42E-07	7.20E-06	2.10
20%	6.76E-06	2.21E-07	6.98E-06	2.13	8.10E-07	7.57E-06	2.05
25%	6.76E-06	3.42E-07	7.10E-06	2.11	1.32E-06	8.08E-06	1.98
30%	6.76E-06	5.11E-07	7.27E-06	2.09	2.03E-06	8.79E-06	1.90
35%	6.76E-06	6.81E-07	7.44E-06	2.06	2.96E-06	9.72E-06	1.81
40%	6.76E-06	8.93E-07	7.65E-06	2.04	4.24E-06	1.10E-05	1.70
45%	6.76E-06	1.14E-06	7.90E-06	2.00	5.83E-06	1.26E-05	1.59
50%	6.76E-06	1.40E-06	8.16E-06	1.97	8.24E-06	1.50E-05	1.45

Table L.36 Reliability Index connected to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 2943 kN.

		γ'			k		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)	VAR ($Y_{top}^{current}$) (m^2)	VAR {g(Y_{top})} (m^2)	Reliability Index (β)
5%	6.76E-06	2.50E-11	6.76E-06	2.17	0.00E+00	6.76E-06	2.17
10%	6.76E-06	2.50E-11	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
15%	6.76E-06	2.50E-11	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
20%	6.76E-06	1.00E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
25%	6.76E-06	1.00E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
30%	6.76E-06	2.25E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
35%	6.76E-06	2.25E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
40%	6.76E-06	4.00E-10	6.76E-06	2.17	1.00E-10	6.76E-06	2.17
45%	6.76E-06	4.00E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17
50%	6.76E-06	6.25E-10	6.76E-06	2.17	2.25E-10	6.76E-06	2.17

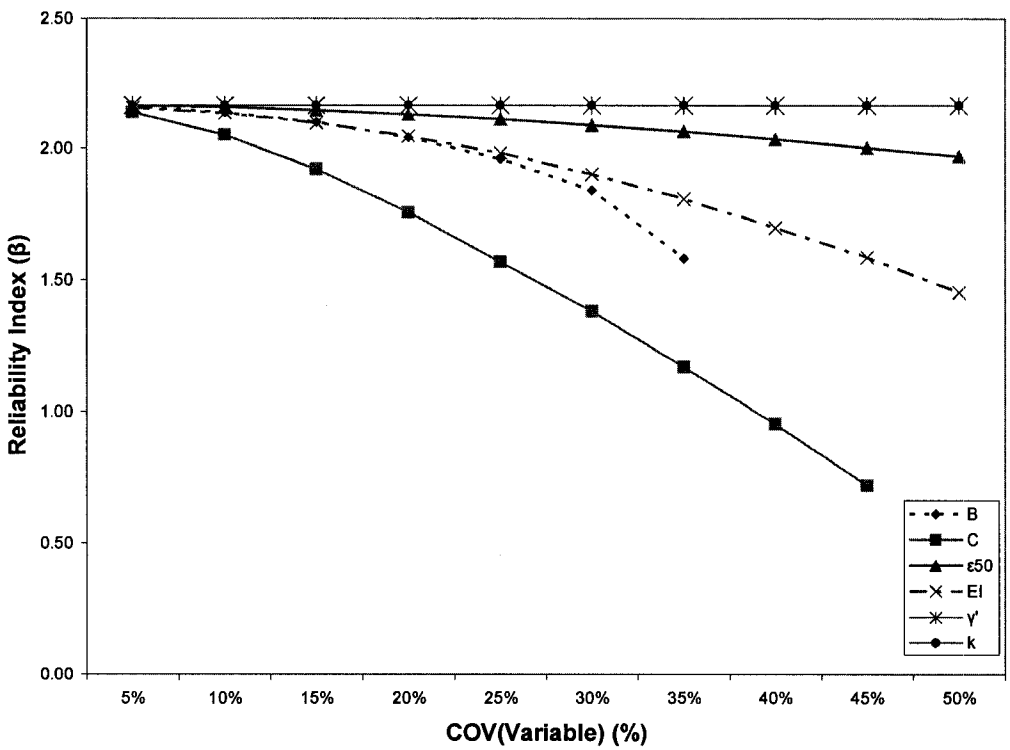

Fig. L.16 Reliability Index (β) connected to Y_{Top} for varying COV(random variable) in fixed head long (10T) pile group with spacing (5D) at 2943 kN lateral load.

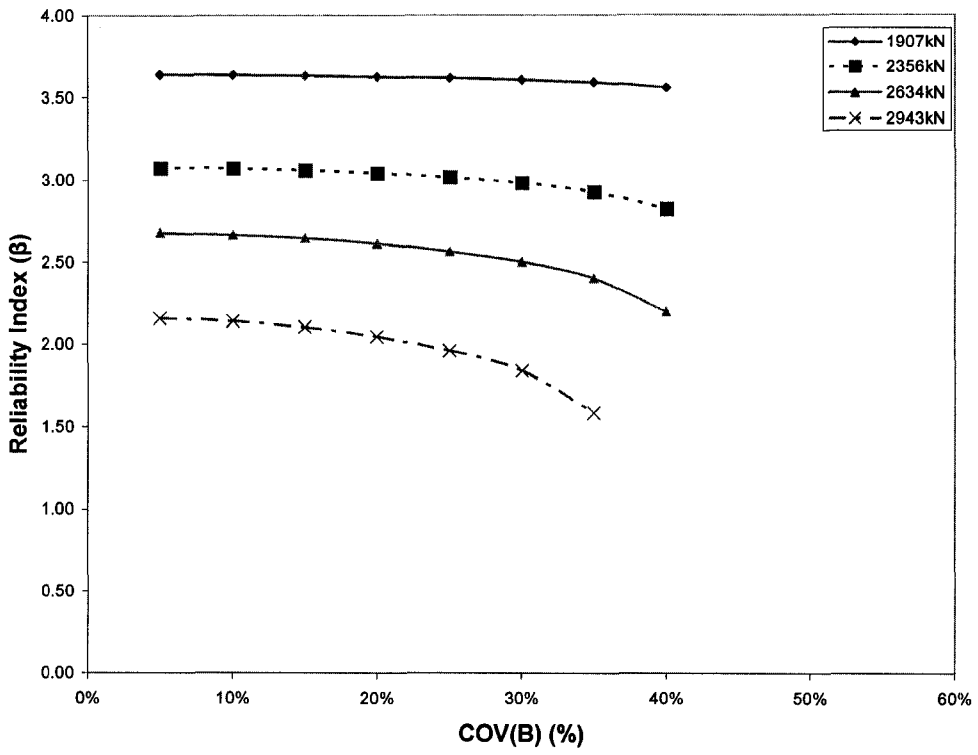

Fig. L.17 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'B'.

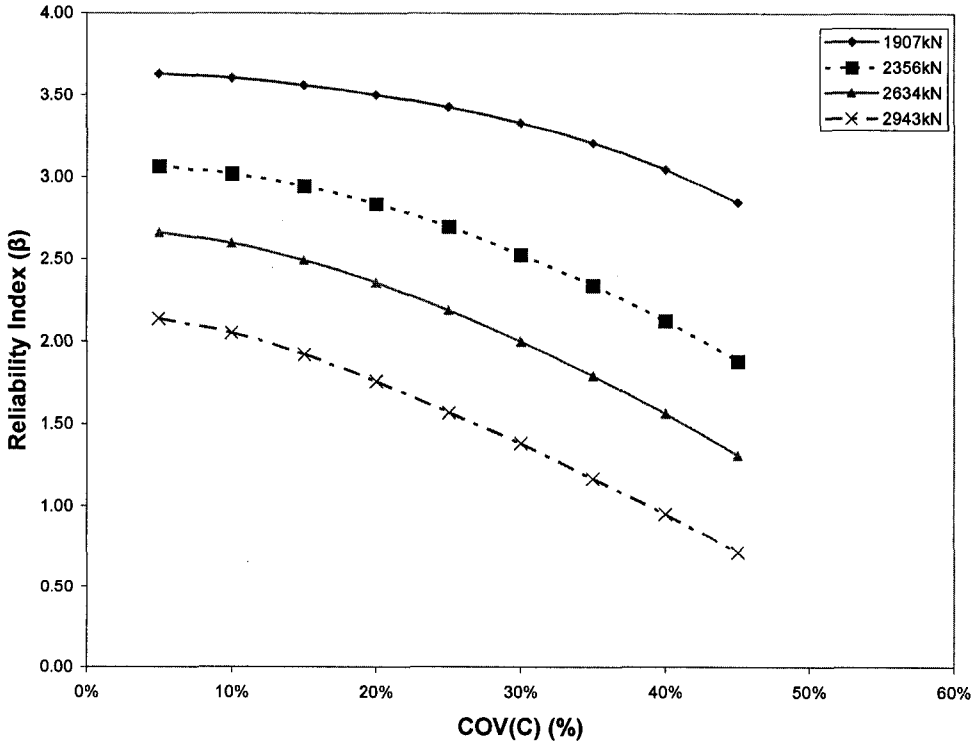

Fig. L.18 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'C'.

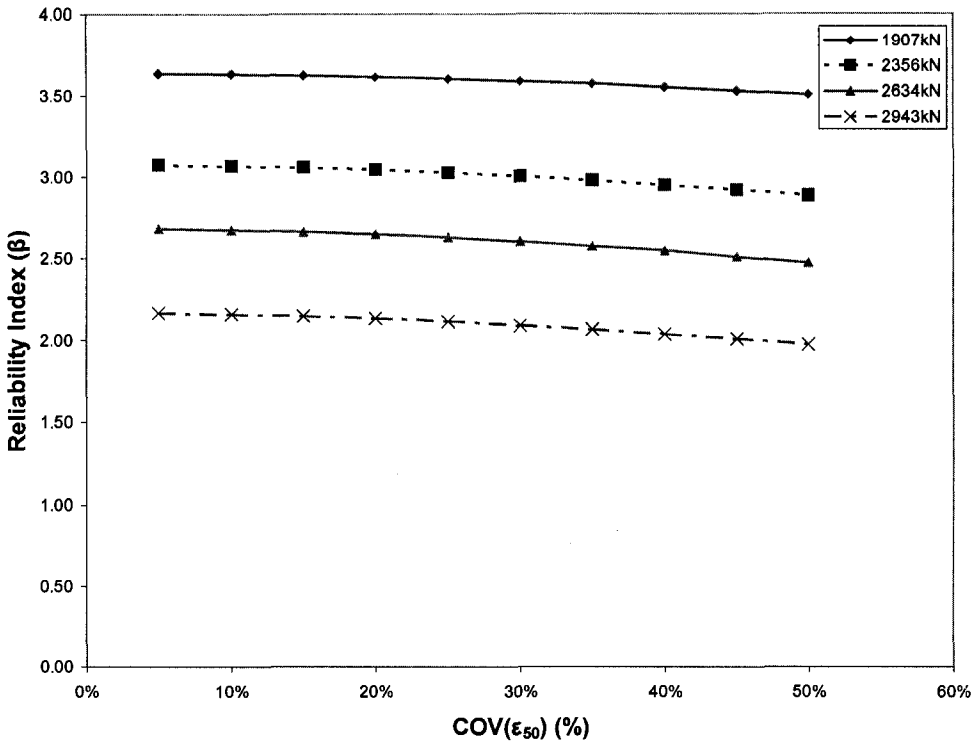

Fig. L.19 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}'.

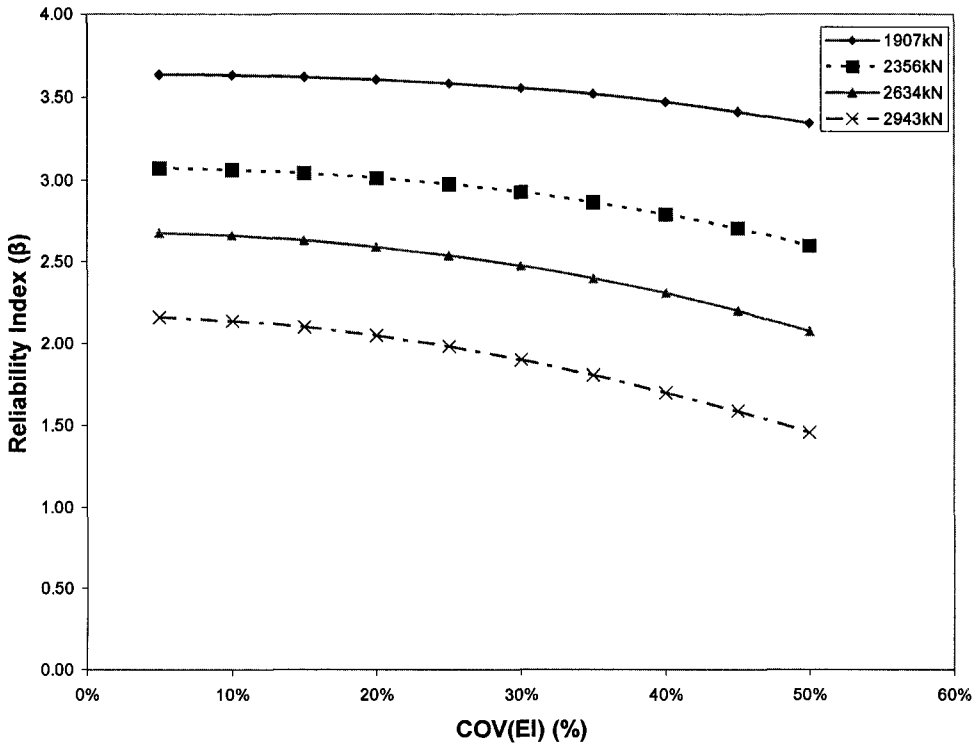

Fig. L.20 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'EI'.

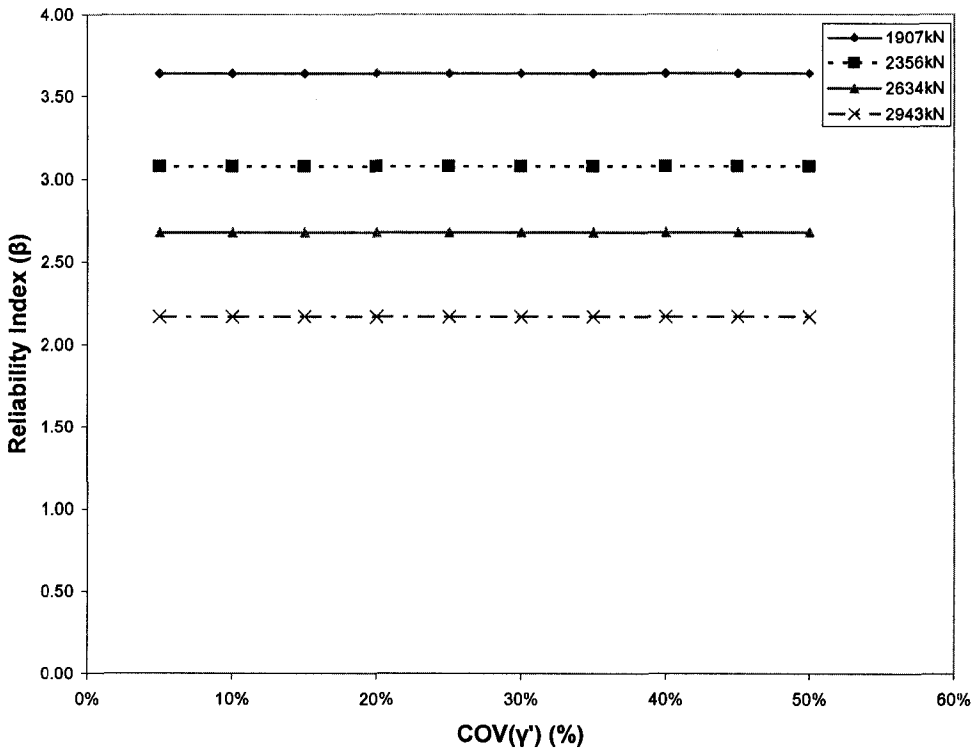

Fig. L.21 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'γ''.

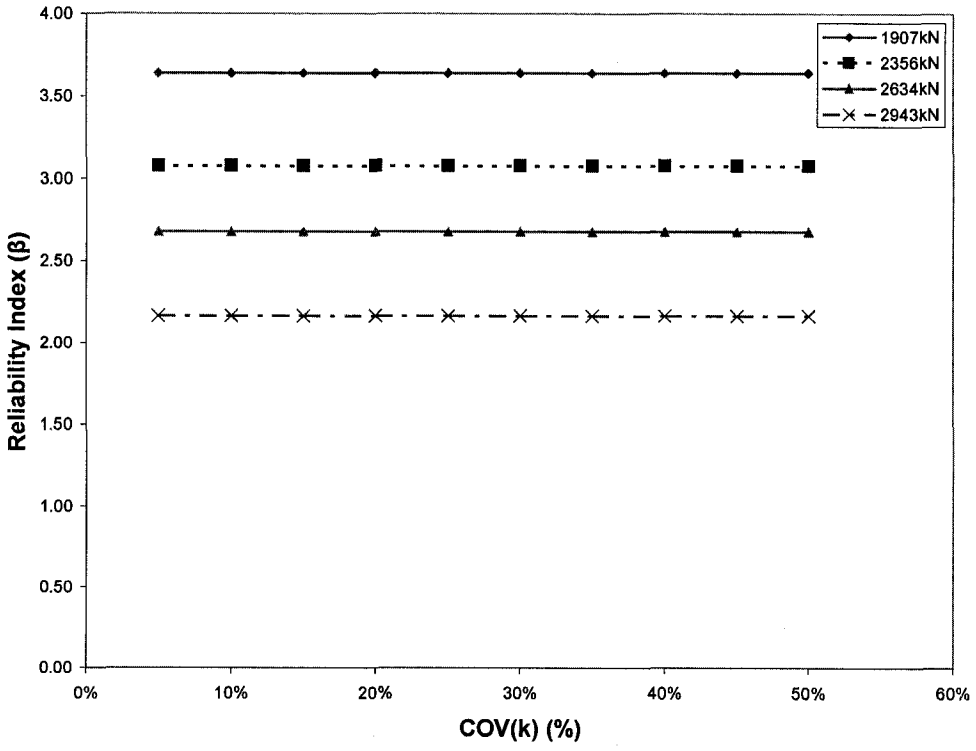

Fig. L.22 Reliability Index related to Y_{Top} for fixed head long (10T) pile group with spacing (5D) and with varying 'k'.

L.2.2 Reliability analysis for ultimate limit state (M_{Max})

For lateral load 1907 kN

$$g(M_{Max})^{o} = M_{Max}^{Resist_o} - M_{Max}^{Current_o} = 815.88 \text{ kN.m}$$

$$VAR(M_{Max}^{Resist}) = 31969.44 \text{ (kN.m)}^2$$

Table L.37 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 1907 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR ($M_{Max}^{Current}$) $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0841	31969.524	4.56	0.275625	31969.716	4.56
10%	31969.44	0.140625	31969.581	4.56	2.3716	31971.812	4.56
15%	31969.44	0.1089	31969.549	4.56	6.9169	31976.357	4.56
20%	31969.44	0.065025	31969.505	4.56	14.6689	31984.109	4.56
25%	31969.44	0.00169	31969.442	4.56	10.44484	31979.885	4.56
30%	31969.44	0.3844	31969.824	4.56	41.7316	32011.172	4.56
35%	31969.44	2.030625	31971.471	4.56	60.762025	32030.202	4.56
40%	31969.44	9.5481	31978.988	4.56	82.81	32052.250	4.56
45%	31969.44	Failed	Failed	Failed	105.4729	32074.913	4.56
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table L.38 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 1907 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.04	31969.480	4.56	0.0025	31969.443	4.56
10%	31969.44	0.0016	31969.442	4.56	0.2116	31969.652	4.56
15%	31969.44	0.003025	31969.443	4.56	0.680625	31970.121	4.56
20%	31969.44	0.0256	31969.466	4.56	1.3924	31970.832	4.56
25%	31969.44	0.025	31969.465	4.56	0.94249	31970.382	4.56
30%	31969.44	0.1089	31969.549	4.56	3.478225	31972.918	4.56
35%	31969.44	0.1936	31969.634	4.56	4.7089	31974.149	4.56
40%	31969.44	0.2916	31969.732	4.56	6.1009	31975.541	4.56
45%	31969.44	0.3364	31969.776	4.56	7.535025	31976.975	4.56
50%	31969.44	0.36	31969.800	4.56	9.1809	31978.621	4.56

Table L.39 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 1907 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	1E-04	31969.440	4.56	4.00E-04	31969.440	4.56
10%	31969.44	0.000225	31969.440	4.56	1.60E-03	31969.442	4.56
15%	31969.44	0.000625	31969.441	4.56	3.02E-03	31969.443	4.56
20%	31969.44	0.001225	31969.441	4.56	1.00E-02	31969.450	4.56
25%	31969.44	0.00081	31969.441	4.56	5.76E-03	31969.446	4.56
30%	31969.44	0.003025	31969.443	4.56	2.25E-02	31969.463	4.56
35%	31969.44	0.004225	31969.444	4.56	3.42E-02	31969.474	4.56
40%	31969.44	0.0049	31969.445	4.56	4.84E-02	31969.488	4.56
45%	31969.44	0.0064	31969.446	4.56	9.00E-02	31969.530	4.56
50%	31969.44	0.0081	31969.448	4.56	1.89E-01	31969.629	4.56

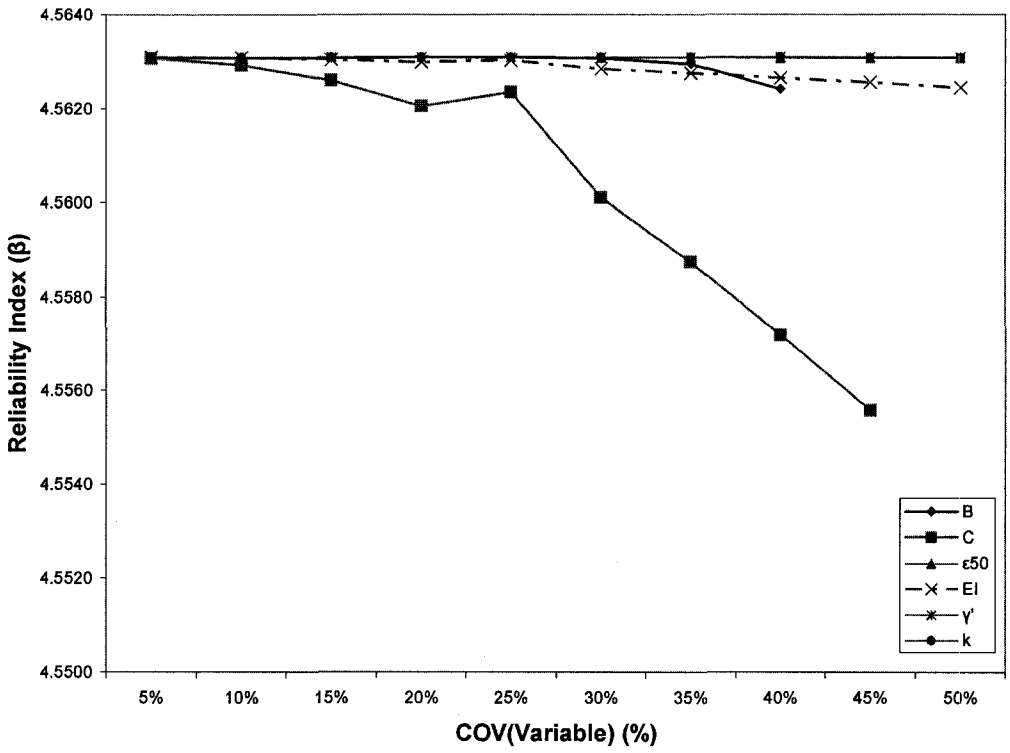

Fig. L.23 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (5D) at 1907 kN lateral load.

For lateral load 2356 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 789.5 \text{ kN.m}$$

Table L.40 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 2356 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.2025	31969.64	4.42	9	31978.44	4.41
10%	31969.44	1.21	31970.65	4.42	37.638225	32007.08	4.41
15%	31969.44	3.61	31973.05	4.42	61.074225	32030.51	4.41
20%	31969.44	7.5625	31977.00	4.42	87.6096	32057.05	4.41
25%	31969.44	14.0625	31983.50	4.41	117.2889	32086.73	4.41
30%	31969.44	20.25	31989.69	4.41	152.15223	32121.59	4.41
35%	31969.44	34.2225	32003.66	4.41	189.0625	32158.50	4.40
40%	31969.44	74.8225	32044.26	4.41	226.5025	32195.94	4.40
45%	31969.44	Failed	Failed	Failed	254.4025	32223.84	4.40
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table L.41 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 2356 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.9025	31970.34	4.42	1.5625	31971.00	4.42
10%	31969.44	3.4225	31972.86	4.42	5.76	31975.20	4.42
15%	31969.44	8.1225	31977.56	4.41	12.6025	31982.04	4.41
20%	31969.44	13.69	31983.13	4.41	23.3289	31992.77	4.41
25%	31969.44	18.447025	31987.89	4.41	36.542025	32005.98	4.41
30%	31969.44	16.81	31986.25	4.41	38.254225	32007.69	4.41
35%	31969.44	14.8225	31984.26	4.41	39.879225	32009.32	4.41
40%	31969.44	12.6025	31982.04	4.41	40.768225	32010.21	4.41
45%	31969.44	10.89	31980.33	4.41	41.6025	32011.04	4.41
50%	31969.44	8.7025	31978.14	4.41	41.6025	32011.04	4.41

Table L.42 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 2356 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.42	2.50E-03	31969.44	4.42
10%	31969.44	0.0025	31969.44	4.42	2.50E-03	31969.44	4.42
15%	31969.44	0.0025	31969.44	4.42	2.50E-03	31969.44	4.42
20%	31969.44	0.0225	31969.46	4.42	2.50E-03	31969.44	4.42
25%	31969.44	0.0225	31969.46	4.42	2.50E-03	31969.44	4.42
30%	31969.44	0.0225	31969.46	4.42	0.00E+00	31969.44	4.42
35%	31969.44	0.0225	31969.46	4.42	0.00E+00	31969.44	4.42
40%	31969.44	0.0625	31969.50	4.42	0.00E+00	31969.44	4.42
45%	31969.44	0.0625	31969.50	4.42	2.50E-03	31969.44	4.42
50%	31969.44	0.0625	31969.50	4.42	2.50E-03	31969.44	4.42

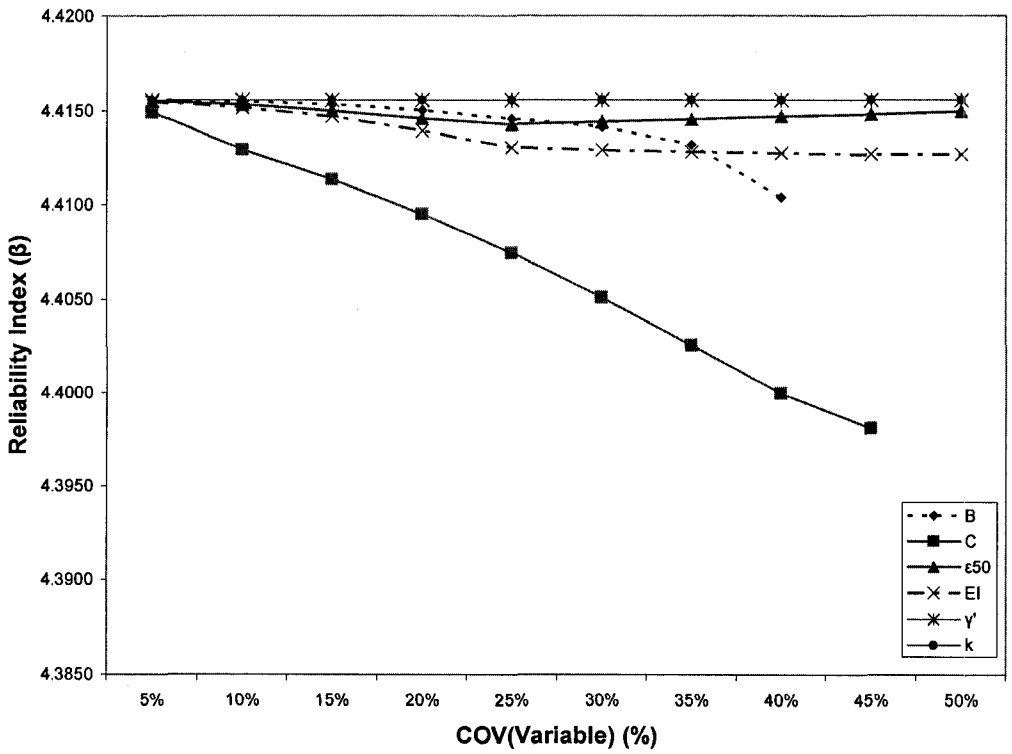

Fig. L.24 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (5D) at 2356 kN lateral load.

For lateral load 2634 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 771.6 \text{ m}$$

Table L.43 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 2634 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.81	31970.25	4.32	12.25	31981.69	4.31
10%	31969.44	3.8025	31973.24	4.32	50.41	32019.85	4.31
15%	31969.44	9.9225	31979.36	4.31	116.64	32086.08	4.31
20%	31969.44	19.36	31988.80	4.31	190.44	32159.88	4.30
25%	31969.44	35.4025	32004.84	4.31	232.5625	32202.00	4.30
30%	31969.44	57.0025	32026.44	4.31	277.2225	32246.66	4.30
35%	31969.44	98.01	32067.45	4.31	325.8025	32295.24	4.29
40%	31969.44	220.5225	32189.96	4.30	349.69	32319.13	4.29
45%	31969.44	Failed	Failed	Failed	504.0025	32473.44	4.28
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table L.44 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 2634 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.5625	31970.00	4.32	1.21	31970.65	4.32
10%	31969.44	2.56	31972.00	4.32	5.29	31974.73	4.32
15%	31969.44	5.76	31975.20	4.32	11.56	31981.00	4.31
20%	31969.44	10.5625	31980.00	4.31	20.25	31989.69	4.31
25%	31969.44	16.4025	31985.84	4.31	32.49	32001.93	4.31
30%	31969.44	26.01	31995.45	4.31	48.3025	32017.74	4.31
35%	31969.44	36.6025	32006.04	4.31	68.0625	32037.50	4.31
40%	31969.44	43.56	32013.00	4.31	90.25	32059.69	4.31
45%	31969.44	37.21	32006.65	4.31	93.1225	32062.56	4.31
50%	31969.44	30.25	31999.69	4.31	92.16	32061.60	4.31

Table L.45 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 2634 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.32	2.50E-03	31969.44	4.32
10%	31969.44	0.01	31969.45	4.32	2.50E-03	31969.44	4.32
15%	31969.44	0.01	31969.45	4.32	2.50E-03	31969.44	4.32
20%	31969.44	0.0225	31969.46	4.32	2.50E-03	31969.44	4.32
25%	31969.44	0.04	31969.48	4.32	2.50E-03	31969.44	4.32
30%	31969.44	0.04	31969.48	4.32	2.50E-03	31969.44	4.32
35%	31969.44	0.0625	31969.50	4.32	2.50E-03	31969.44	4.32
40%	31969.44	0.09	31969.53	4.32	2.50E-03	31969.44	4.32
45%	31969.44	0.09	31969.53	4.32	2.50E-03	31969.44	4.32
50%	31969.44	0.1225	31969.56	4.32	2.50E-03	31969.44	4.32

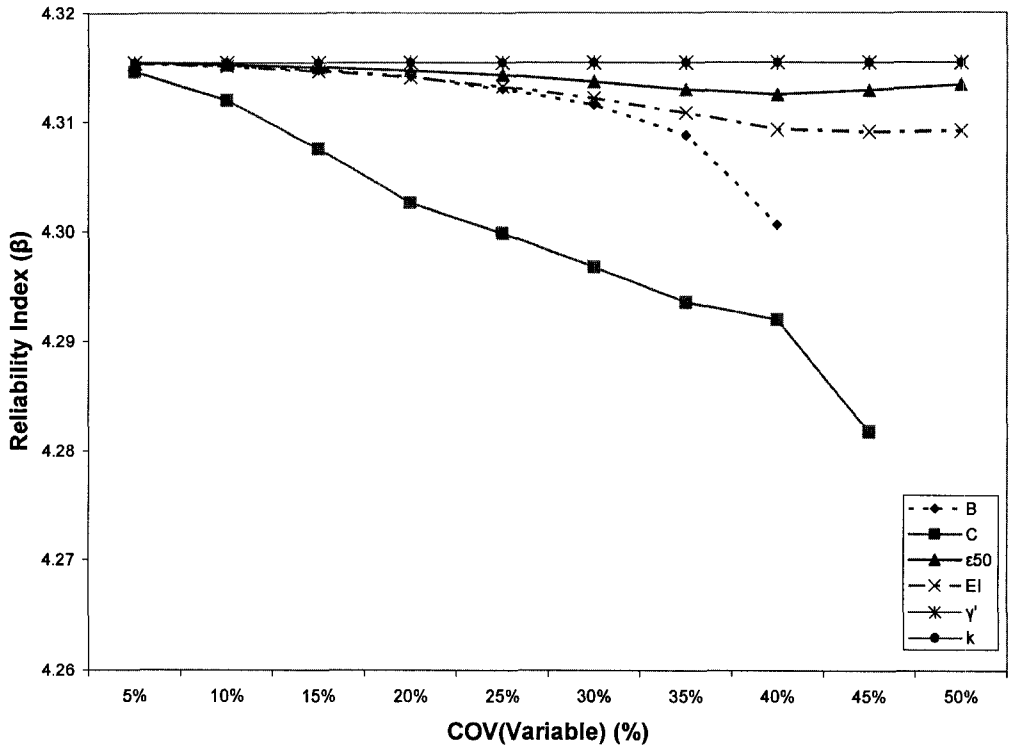

Fig. L.25 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (5D) at 2634 kN lateral load.

For lateral load 2943 kN

$$g(M_{Max})^{o} = M_{Max}^{Resisto} - M_{Max}^{Currento} = 749.6 \text{ kN.m}$$

Table L.46 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'B' and 'C' and applied lateral load 2943 kN.

		B			C		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	2.1025	31971.54	4.19	17.2225	31986.66	4.19
10%	31969.44	9.9225	31979.36	4.19	71.4025	32040.84	4.19
15%	31969.44	26.5225	31995.96	4.19	157.5025	32126.94	4.18
20%	31969.44	53.29	32022.73	4.19	272.25	32241.69	4.17
25%	31969.44	95.0625	32064.50	4.19	410.0625	32379.50	4.17
30%	31969.44	162.5625	32132.00	4.18	495.0625	32464.50	4.16
35%	31969.44	340.4025	32309.84	4.17	522.1225	32491.56	4.16
40%	31969.44	Failed	Failed	Failed	873.2025	32842.64	4.14
45%	31969.44	Failed	Failed	Failed	1831.84	33801.28	4.08
50%	31969.44	Failed	Failed	Failed	Failed	Failed	Failed

Table L.47 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying ε_{50} and EI and applied lateral load 2943 kN.

		ε_{50}			EI		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.36	31969.800	4.19	0.81	31970.250	4.19
10%	31969.44	1.3225	31970.763	4.19	3.8025	31973.243	4.19
15%	31969.44	3.4225	31972.863	4.19	9.61	31979.050	4.19
20%	31969.44	6.0025	31975.443	4.19	16.81	31986.250	4.19
25%	31969.44	9.3025	31978.743	4.19	26.5225	31995.963	4.19
30%	31969.44	14.0625	31983.503	4.19	37.21	32006.650	4.19
35%	31969.44	18.9225	31988.363	4.19	51.1225	32020.563	4.19
40%	31969.44	23.04	31992.480	4.19	67.24	32036.680	4.19
45%	31969.44	30.25	31999.690	4.19	82.81	32052.250	4.19
50%	31969.44	37.21	32006.650	4.19	101.0025	32070.443	4.19

Table L.48 Reliability Index connected to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'γ'' and 'k' and applied lateral load 2943 kN.

		γ'			k		
COV (Variable) (%)	VAR (M_{Max}^{Resist}) $(kN\text{-}m)^2$	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)	VAR $(M_{Max}^{Current})$ $(kN\text{-}m)^2$	VAR $\{g(M_{Max})\}$ $(kN\text{-}m)^2$	Reliability Index (β)
5%	31969.44	0.0025	31969.44	4.19	0.00E+00	31969.44	4.19
10%	31969.44	0.0025	31969.44	4.19	1.00E-02	31969.45	4.19
15%	31969.44	0.01	31969.45	4.19	1.00E-02	31969.45	4.19
20%	31969.44	0.0225	31969.46	4.19	1.00E-02	31969.45	4.19
25%	31969.44	0.04	31969.48	4.19	1.00E-02	31969.45	4.19
30%	31969.44	0.04	31969.48	4.19	1.00E-02	31969.45	4.19
35%	31969.44	0.0625	31969.50	4.19	1.00E-02	31969.45	4.19
40%	31969.44	0.09	31969.53	4.19	1.00E-02	31969.45	4.19
45%	31969.44	0.1225	31969.56	4.19	1.00E-02	31969.45	4.19
50%	31969.44	0.1225	31969.56	4.19	1.00E-02	31969.45	4.19

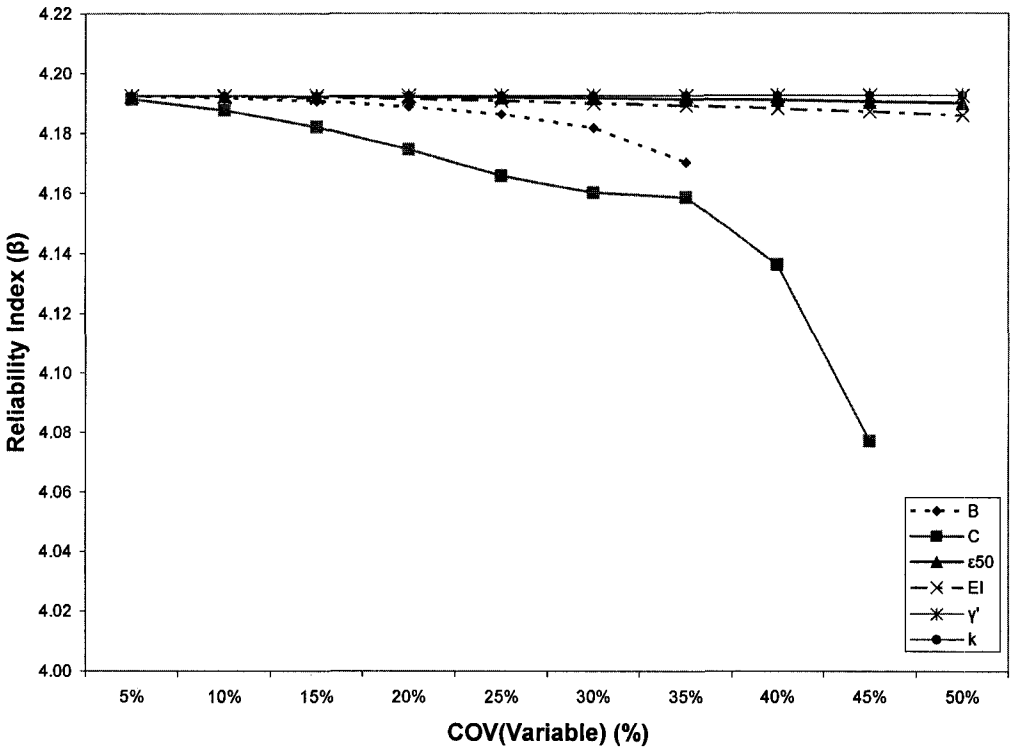

Fig. L.26 Reliability Index (β) connected to M_{Max} for varying COV(random variable) in Pile C of fixed head long (10T) pile group with spacing (5D) at 2943 kN lateral load.

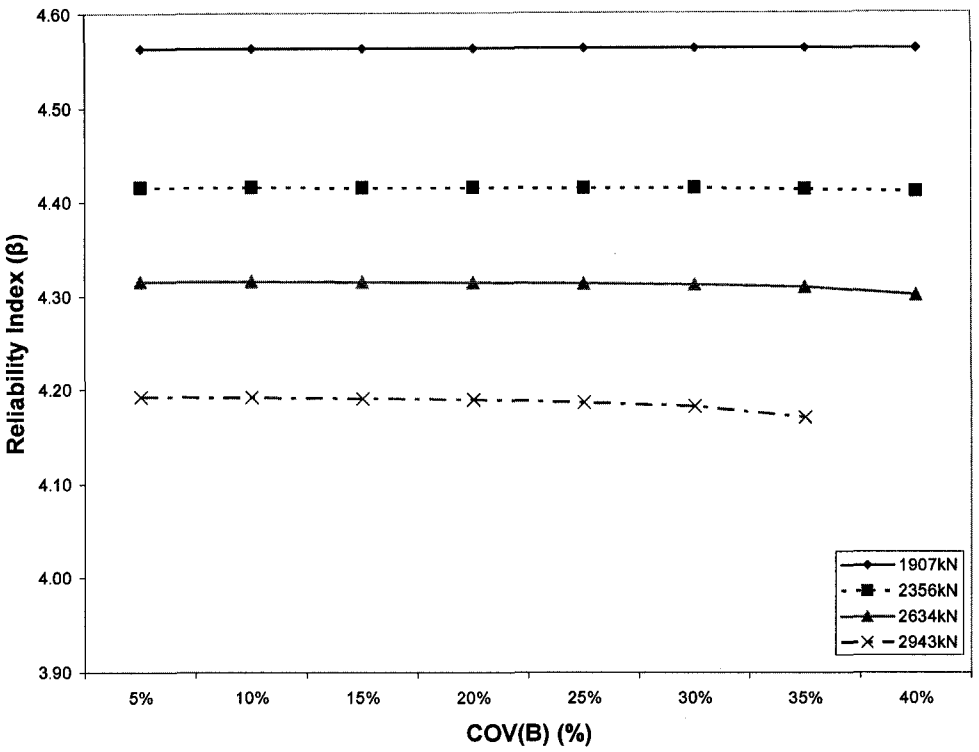

Fig. L.27 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'B'.

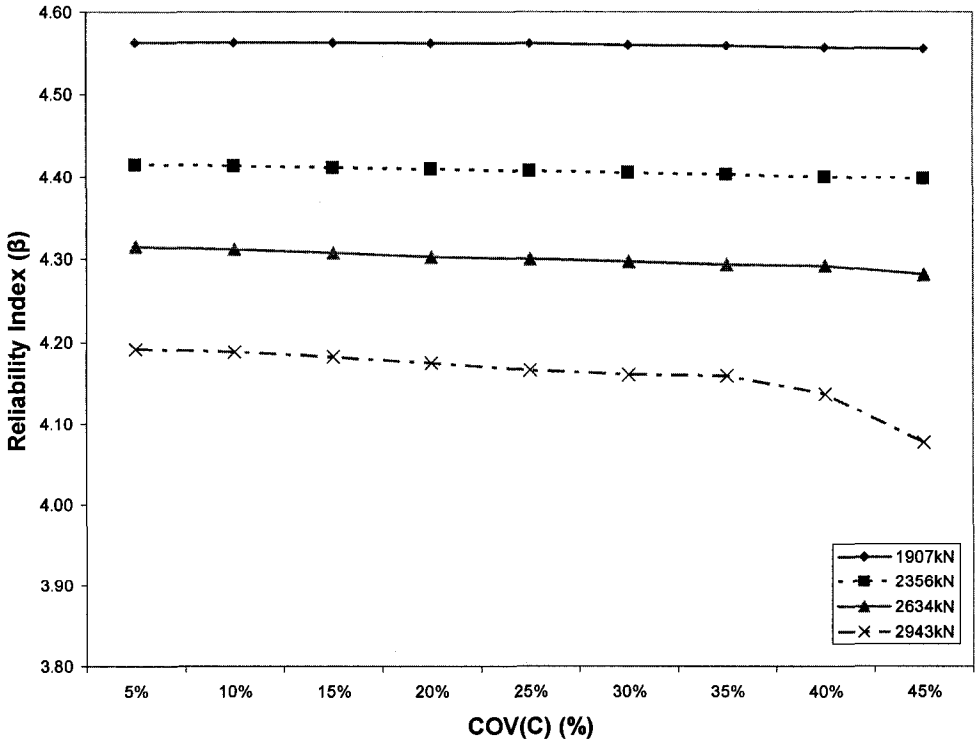

Fig. L.28 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'C'.

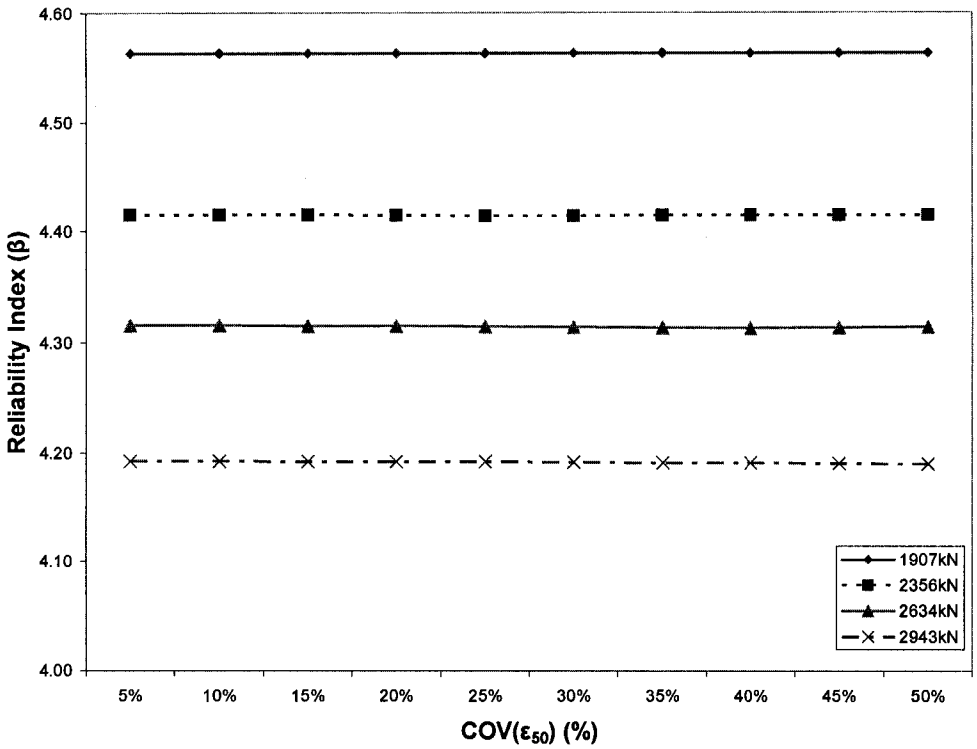

Fig. L.29 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'ε_{50}'.

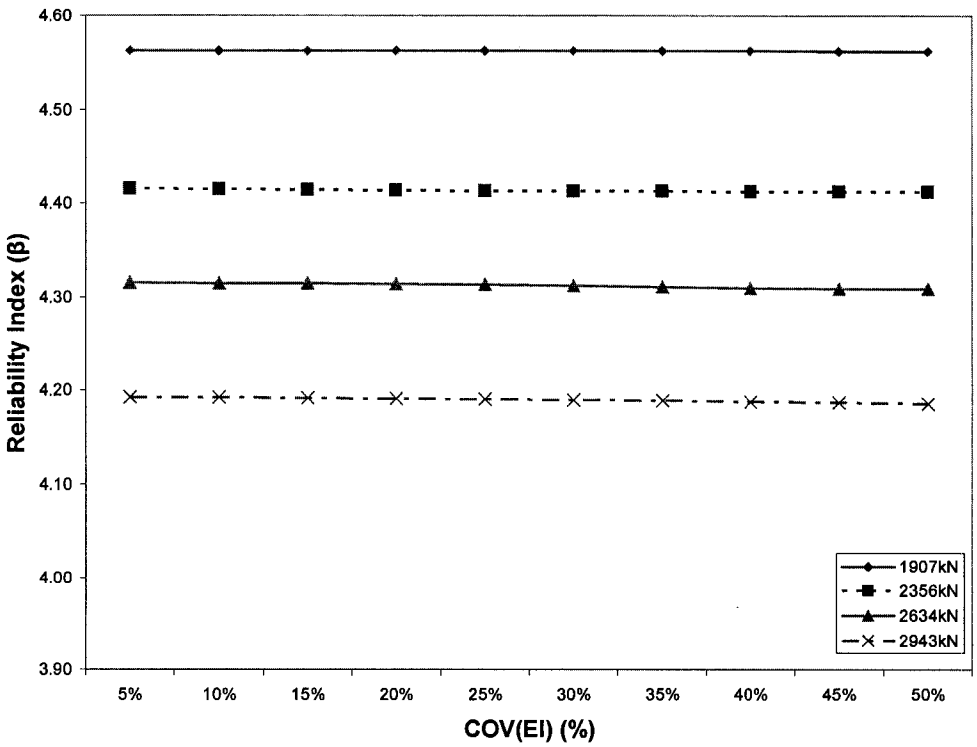

Fig. L.30 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'EI'.

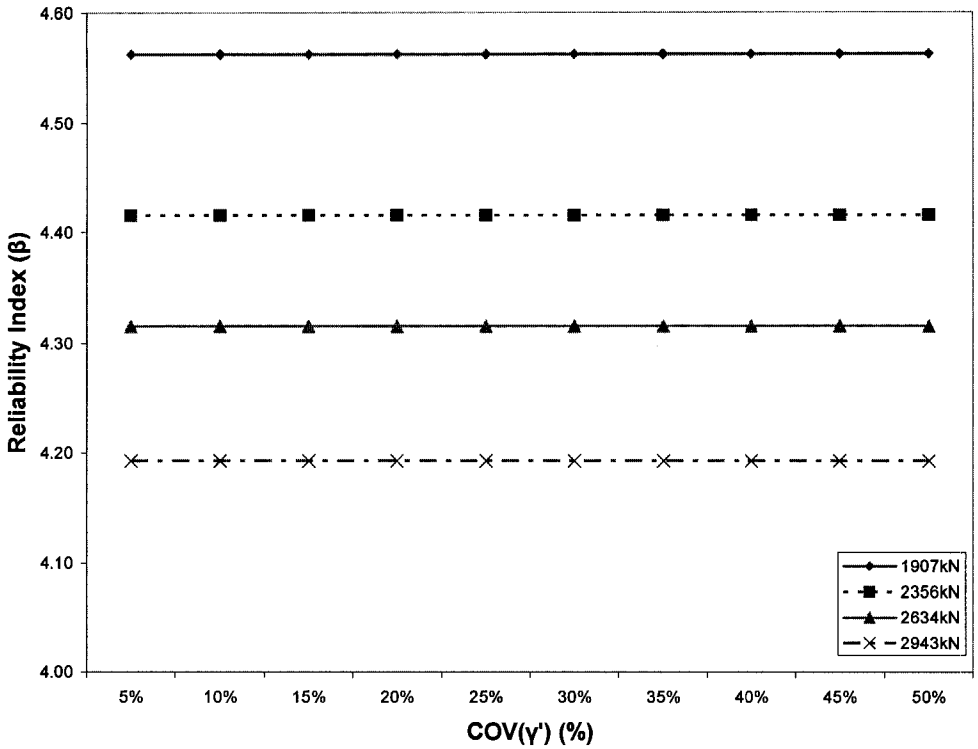

Fig. L.31 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'γ''.

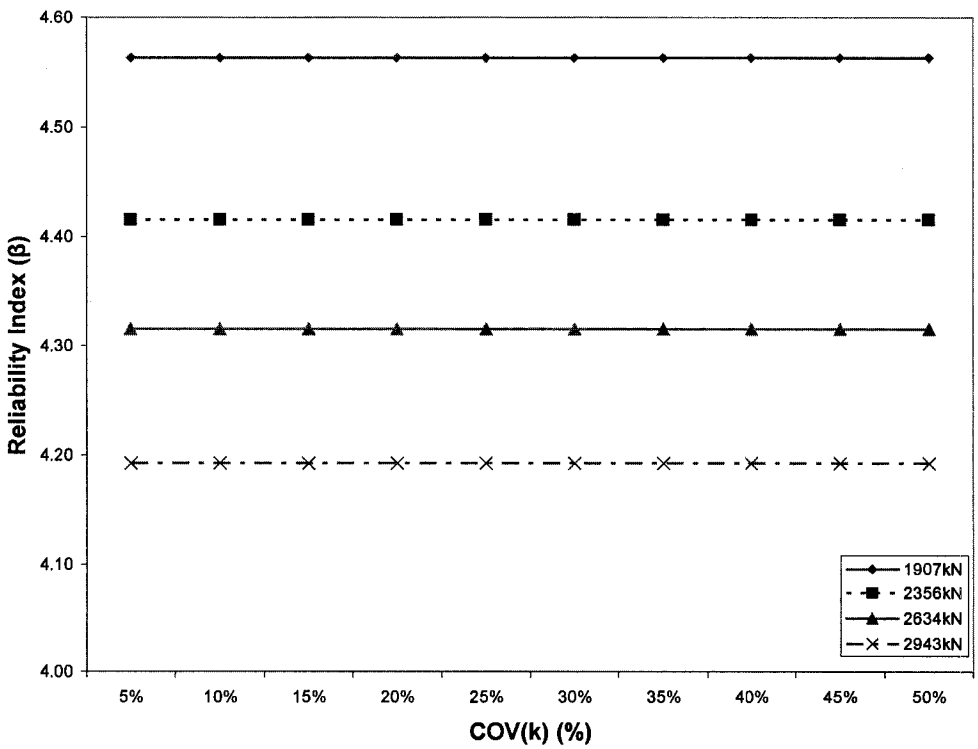

Fig. L.32 Reliability Index related to M_{Max} for leading row (Pile C) in fixed head long (10T) pile group with spacing (5D) and with varying 'k'.

APPENDIX M

COMBINED LOAD ANALYSIS

M.1 Analysis of pile subjected to varying lateral load (P)

Laterally loaded free head single long (10T) pile is analyzed for varying lateral load P by keeping all the other random design variables such as B, C, EI, ε_{50}, γ', and k at their mean value.

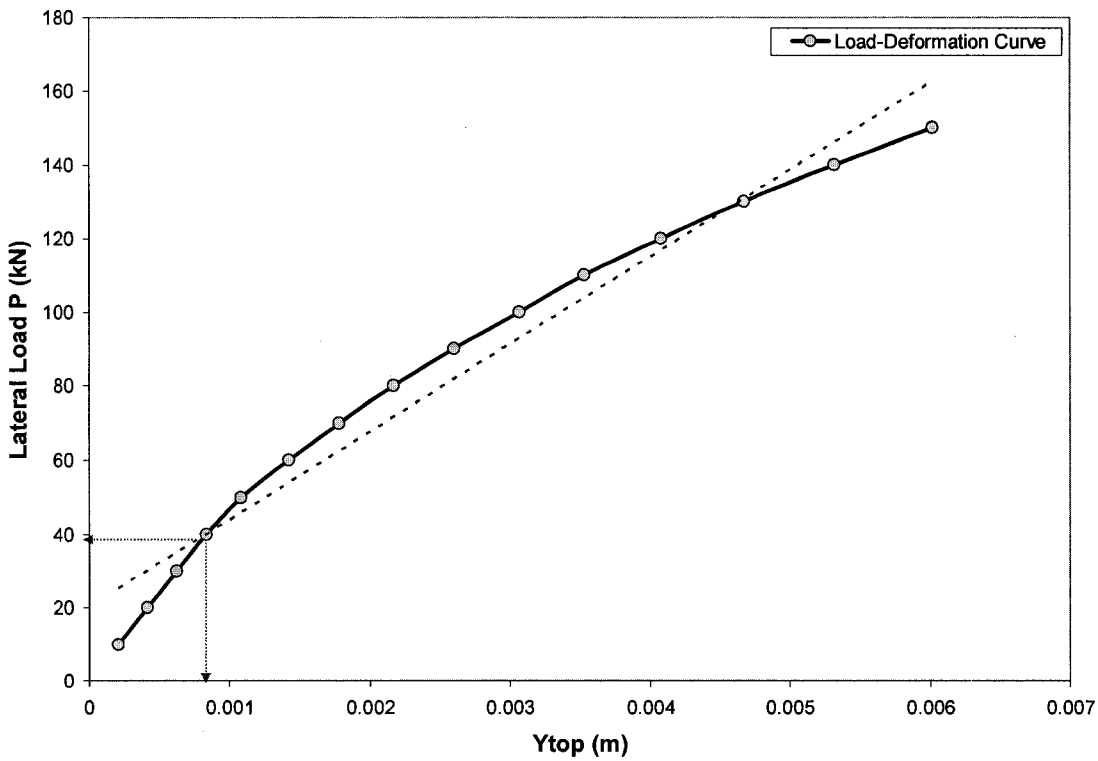

Fig. M.1 Load-Deformation curve for free head single long (10T) pile subjected to varying lateral load P

M.2 Analysis of pile subjected to varying moment (M)

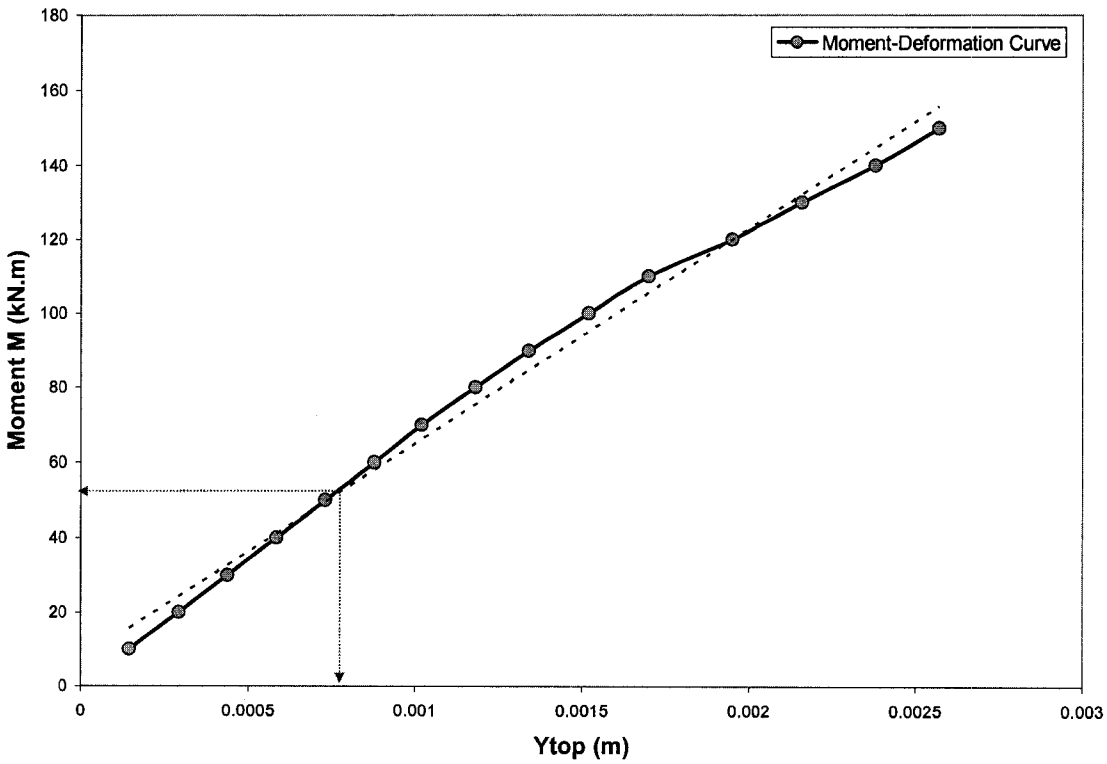

Fig. M.2 Moment-Deformation curve for free head single long (10T) pile subjected to varying moment (M)

M.3 Analysis of pile subjected to varying combined load (P+M)

Tb.M.1 Pile head deflection (Y_{Top}) for free head single long (10T) pile subjected to varying linear and non-linear combined load (P+M).

			Linear	Non-Linear
COV (Variable) (%)	Lateral Load P (kN)	Moment M (kN.m)	Pile Head Deflection Y_{Top}^{L}	Pile Head Deflection Y_{Top}^{NL}
50%	16	22.5	0.00065	0.00065
45%	17.6	24.75	0.00072	0.00072
40%	19.2	27	0.00078	0.00078
35%	20.8	29.25	0.00085	0.00085
30%	22.4	31.5	0.00091	0.00091
25%	24	33.75	0.00098	0.00098
20%	25.6	36	0.00104	0.00104
15%	27.2	38.25	0.00111	0.00111
10%	28.8	40.5	0.00117	0.00117
5%	30.4	42.75	0.00124	0.00124
Mean 0	32	45	0.00130	0.001304
5%	33.6	47.25	0.00137	0.00144
10%	35.2	49.5	0.00143	0.00154
15%	36.8	51.75	0.00150	0.00166
20%	38.4	54	0.00156	0.00176
25%	40	56.25	0.00163	0.00186
30%	41.6	58.5	0.00169	0.00196
35%	43.2	60.75	0.00176	0.00206
40%	44.8	63	0.00182	0.00216
45%	46.4	65.25	0.00189	0.00227
50%	48	67.5	0.00195	0.00238

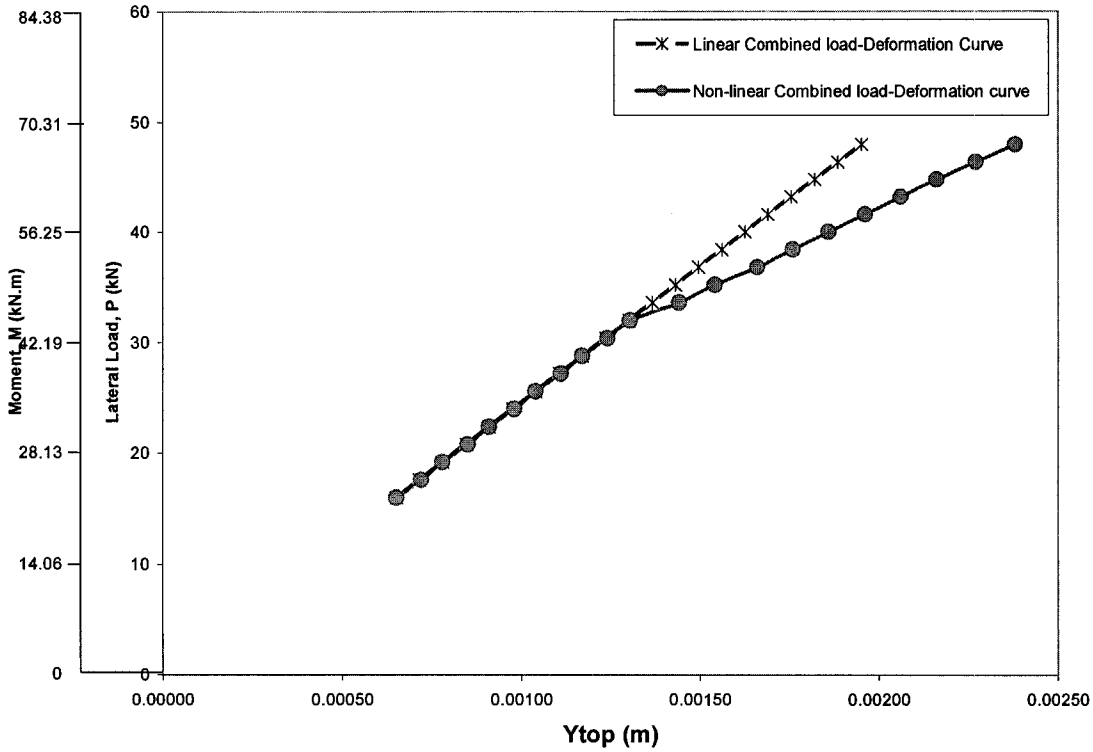

Fig. M.3 Linear and non-linear Load-Deformation curve for free head single long (10T) pile.

M.3.1 Probabilistic modeling of free head single long (10T) pile subjected to varying linear and non-linear combined loading (P+M)

Tb.M.2 COV(Y_{Top}^{L}) and COV(Y_{Top}^{NL}) for free head single long (10T) pile subjected to varying linear and non-linear combined load (P+M).

			Linear		Non-Linear	
COV (Variable) (%)	Var(P) $(kN)^2$	Var(M) $(kN.m)^2$	Var(Y_{Top}^{L}) (m^2)	COV(Y_{Top}^{L}) (%)	Var(Y_{Top}^{NL}) (m^2)	COV(Y_{Top}^{NL}) (%)
5%	2.56	5.0625	8.45E-09	7.07%	2.00E-08	10.88%
10%	10.24	20.25	3.38E-08	14.14%	6.84E-08	20.13%
15%	23.04	45.5625	7.61E-08	21.21%	1.51E-07	29.92%
20%	40.96	81	1.35E-07	28.28%	2.59E-07	39.16%
25%	64	126.5625	2.11E-07	35.36%	3.87E-07	47.87%
30%	92.16	182.25	3.04E-07	42.43%	5.51E-07	57.11%
35%	125.44	248.0625	4.14E-07	49.50%	7.32E-07	65.82%
40%	163.84	324	5.41E-07	56.57%	9.52E-07	75.06%
45%	207.36	410.0625	6.84E-07	63.64%	1.20E-06	84.31%
50%	256	506.25	8.45E-07	70.71%	1.50E-06	94.10%

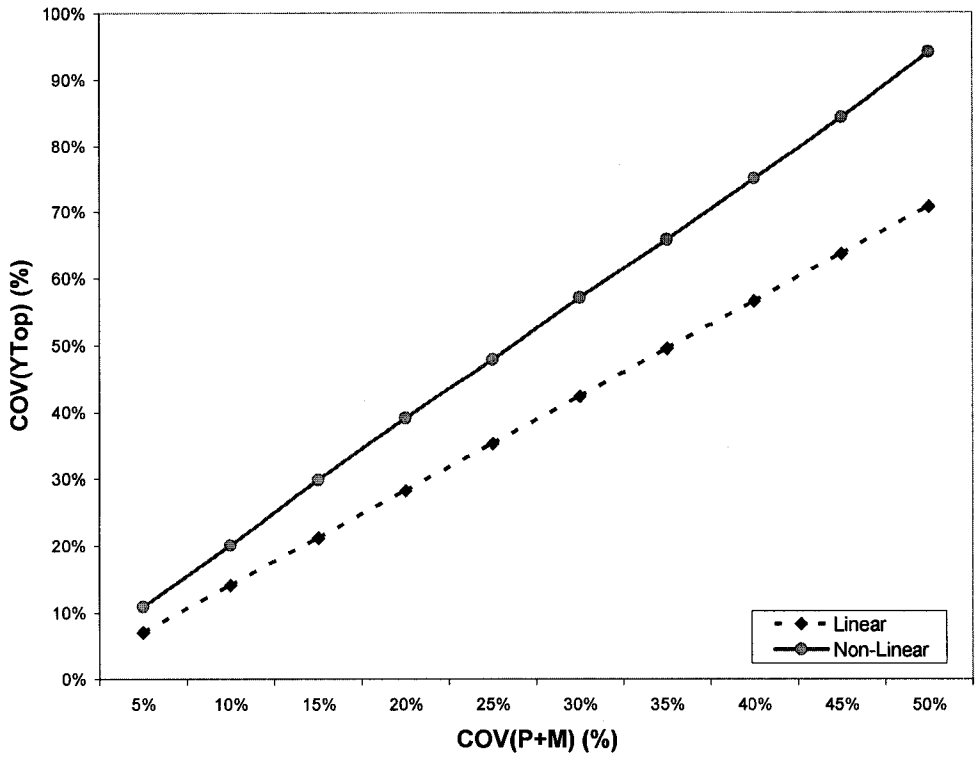

Fig. M.4 COV(YTop) for COV(P+M) in free head single long (10T) pile subjected to varying linear and non-linear combined loading (P+M).

M.3.2 reliability analysis of free head single long (10T) pile subjected to linear and non-linear combined loading (P+M)

$$g(Y_{top})^{o} = Y_{top}^{Resist_o} - Y_{top}^{Current_o} = 0.0117 \text{ m} \quad \text{and} \quad VAR(Y_{top}^{Resist}) = 6.76E\text{-}06 \text{ m}^2$$

Tb.M.3 Reliability Index (β) connected to Y_{Top} for free head single long (10T) pile subjected to varying linear and non-linear combined loading (P+M).

		Linear			Non-Linear		
COV (Variable) (%)	VAR (Y_{top}^{Resist}) (m^2)	VAR $(Y_{top}^{current})_L$ (m^2)	VAR $\{g(Y_{top})\}_L$ (m^2)	Reliability Index (β_L)	VAR $(Y_{top}^{current})_{NL}$ (m^2)	VAR $\{g(Y_{top})\}_{NL}$ (m^2)	Reliability Index (β_{NL})
5%	6.76E-06	8.45E-09	6.77E-06	4.50	2.00E-08	6.78E-06	4.49
10%	6.76E-06	3.38E-08	6.79E-06	4.49	6.13E-08	6.82E-06	4.48
15%	6.76E-06	7.61E-08	6.84E-06	4.47	1.51E-07	6.91E-06	4.45
20%	6.76E-06	1.35E-07	6.90E-06	4.46	2.59E-07	7.02E-06	4.42
25%	6.76E-06	2.11E-07	6.97E-06	4.43	3.87E-07	7.15E-06	4.38
30%	6.76E-06	3.04E-07	7.06E-06	4.40	5.51E-07	7.31E-06	4.33
35%	6.76E-06	4.14E-07	7.17E-06	4.37	7.32E-07	7.49E-06	4.27
40%	6.76E-06	5.41E-07	7.30E-06	4.33	9.52E-07	7.71E-06	4.21
45%	6.76E-06	6.84E-07	7.44E-06	4.29	1.20E-06	7.96E-06	4.15
50%	6.76E-06	8.45E-07	7.61E-06	4.24	1.50E-06	8.26E-06	4.07

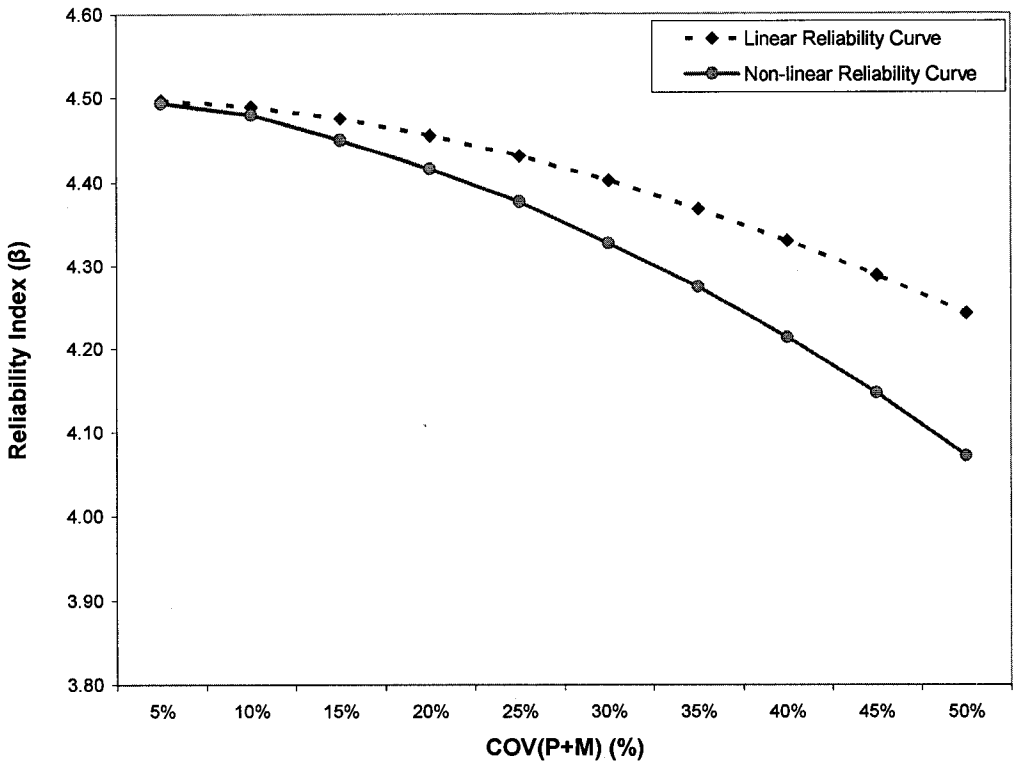

Fig. M.5 Reliability curve connected to Y_{Top} for COV(P+M) in free head single long (10T) pile subjected to varying linear and non-linear combined load (P+M).

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